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Evaluation of Ultra Fine Cigarette Smoke Particles Penetration on 3M 6200 Half Mask Respirators with P-100 Filters

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Thesis submitted to the Statler College of Engineering and Mineral Resources at West Virginia University

in partial fulfillment of the requirements for the degree of

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Abstract

Evaluation of Ultra Fine Cigarette Smoke Particles Penetration on 3M 6200 Half Mask Respirators with P-100 Filters

Selcuk Elhan

This study was aimed to investigate the effectiveness of half mask respirator with double P-100 filters by determining the penetration of cigarette smoke particles. In this study, faceseal leakage of a breathing manikin donned a 3M 6200 half mask elastomeric respirator with double P-100 filters was determined at various test conditions. A full factorial test conditions of 4 sealing conditions (Non-sealed, only nose sealed, nose and chin sealed, and fully sealed), 2 inspiratory breathing types (Constant, cyclic), 4 flowing rates (15, 30, 50, 85 L/min for cyclic; 15, 30, 50, 80 L/min for constant) were employed and each test condition was repeated three times. Ultra fine smoke particles were generated by burning a cigarette in an exposure chamber. For each test condition, particle number concentrations using a P-Trak condensation particle counter were measured, inside and outside of the elastomeric half mask respirator and penetration was calculated as a ratio of two concentrations ($P=C_{in}/C_{out}$).

Our hypothesis claimed that variables of sealing type, breathing flow type, and flowing rate were all significant features which have an effect on penetration percentage of ultrafine cigarette smoke aerosol through 3M 6200 half mask respirator with P-100 filters. Non-sealed and partially sealed conditions showed that the penetration percentage ($P=C_{in}/C_{out}$) of cigarette smoke was more than 0.03% (i.e., penetration $\geq$ 0.03%, which is an acceptable criterion, and showed statistically significant result (p-value: 7.58 E-20< α, which was assigned as 0.05). However, fully-

sealed test results were measured the smoke penetration percentage equal or lower than 0.03% (penetration $\leq$0.03%). Our findings showed that 3M 6200 half mask respirator with P-100 filters served proper protection against ultrafine cigarette smoke aerosol.

This report consists of 5 chapters. In Chapter 1, introduction part was described in detail, 3M 6200 half mask respirator and P-100 filters were explained. Chapter 2 starts with a brief literature review of similar researches. In Chapter 3, experimental set-up was demonstrated. In Chapter 4, the collected data were presented along with the statistical test results analyzed with ANOVA one-way analysis of variance in order to find out which variables are significant in this study.

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Chapter 1: Introduction

Occupational Safety and Health Administration (OSHA) defines a respirator as a device that protects employees from inhalation of dangerous substances such as, chemicals and infectious particles (OSHA,1970). OSHA states that choosing an appropriate respirator is the most crucial issue. The selected respirator needs to be sure that it can be used safely for performing tasks in a hazardous environmental condition. Before choosing an appropriate respirator, it's essential to identify hazard type and airborne concentration in the working premises. Respirators to protect employees from airborne particle exposures operate in various ways such as, filtering particles from the air, purifying the air chemically, or providing clean air from an outside air supply.

According to National Institute for Occupational Safety and Health (NIOSH), P-100 filter has more than 99.97% filtering efficiency. Our study revealed that particle penetration efficiency depends on sealing conditions of respirator as well. Non-sealed or partially sealed respirator would increase leakage, leading to the increased particle penetration percentages. Half mask respirators are commonly used to protect employees from airborne contaminants causing several adverse health effects.

In this research, combustion of cigarette smoke aerosol was chosen to generate aerosolized ultrafine particles, because no similar research was conducted previously with cigarette smoke aerosol. Most of the similar researches were performed using other types of aerosolized particles, such as combustion of burning paper, wood and plastic, rather than those from cigarette smoke (He et. all, 2013).

Therefore, this study was performed to find out the effectiveness of half mask respirator with dual P-100 filters against ultrafine particles aerosolized from cigarette smoke. In this research, 1 type of half mask respirator (3M 6200 Half Mask) and filter type (3M P-100) was put on a breathing manikin's face.

Three artificial leaks connected with tubes were used to utilize testing measurement terminals on the breathing manikin's head. One tube is specified as simulating human breathing, and the other two tubes are defined as inside and outside of the half mask to enable monitoring measurement spots.

A king size cigarette which was used as a smoke particle generator, was burned on cigarette holder in the testing chamber. The particle number concentration was measured with TSI P-Trak ultra-fine particle counter 8525 (TSI Incorporated, 2013) during the cigarette combustion. Once the particle concentration reached up to the device maximum measurement value of 500000 pt/cc, sampling. Inside and outside of the mask was conducted every minute. When sampling finished, all sampled data were transferred from P-Trak's memory to the computer by a communication cable.

Four sealing conditions were applied on breathing manikin to find out leakage through the mask due to facial hair or different face configuration of the manikin. These 4 different sealing types were described as non-sealed, only nose sealed, nose and chin areas sealed, and fully sealed. Silicone material was applied between half mask and breathing manikin's face to establish different types of sealing conditions.

Four cyclic flows with mean inspiratory flow (MIF) rates of 15,30,50, and 85 L/min were tested for each sealing conditions.

There are limited data available regarding particle penetration and faceseal leakage under cyclic breathing flow type. In addition, only a few information is available about filters and faceseal penetration under actual human breathing conditions. In this study, 4 cyclic breathing flows were tested with 4 sealing conditions.

Continuous flow does not represent an actual human breathing pattern; therefore, cyclic flow types were used to test closely actual human breathing features.

1.1 3M 6200 Half Mask Features

Figure 1: Example of an elastomeric half mask respirator (Source 3M)

Half mask elastomeric respirator is used commonly due to advantages of its comfort and convenience. The facepiece respirator is lightweight, very soft, comfortable, having easy adjustable head straps. This respirator can be disassembled, cleaned and reusable. Cartridges and filters could be replaced, if needed, therefore, these features utilize respirator cost effectiveness.

According to NIOSH approval, 3M 6200 respirator family enables to produce negative pressure on air purifying filter to preserve variety of gases, vapors, and particulate hazards. Dual airline system utilizes to connect double variety of cartridges and filters. In this course of tests medium size of half mask respirator was put on manikin's head with adjusted head straps. Tests were performed in an exposure chamber at various test conditions.

1.2 P-100 Filter Performance

Figure 2: Example of a P-100 filter (Source:3M)

P-100 filter is classified as Advanced Electret Media (AEM) which is lightweight and has easy inhaling features. In addition, the 2091 filters are capable of filtering oil and non-oil based particulate contaminants. P-100 filter is one of the Air Purifying Filters (APR) which has either P, N, R product letters, corresponding to fine particles filtering efficiency of 100%, 99%, and 95%, respectively. According to the product manual, this filter is reusable and has an ability to filter fine particulates in the fire smoke. However, it cannot filter gases, for instance, carbon monoxide. In order to satisfy proper protection, users must wear facepiece respirators very tight to avoid faceseal leakage.

Chapter 2: Literature Review

2.1 Ultrafine Particles

Particles that are less than 100 nm in diameter, commonly determined as ultrafine. Ultrafine particles are known as particulate matter of nanoscale size and they could be stationary or mobile. Ultrafine particles are universal matters and present almost everywhere. (Donaldson, Stone, Renwick, & MacNee, 2001).

Ultrafine particles are commonly generated from combustion processes (Donaldson, Stone, Renwick, & MacNee, 2001). In this study a cigarette was burnt to produce ultrafine cigarette smoke particles.

2.2 Ultrafine Particles in Cigarette Smoke

Studying the features of the particle size distribution of cigarette smoke can help us to provide some facts about smoke aerosol characteristics. Particle size distribution of mainstream cigarette smoke was generated by a smoking machine and was measured by an Electrical low-pressure impactor (ELPI). The results revealed the aerodynamic diameters of mainstream smoke particles vary from 0.021 to 1.956 μm. (li et al., 2014)

Cigarette smoke is a complex mixture of smoke components, generally described by diameter size-based distribution. Some studies concluded that cigarette smoke has potentially pathogenic ingredients, such as particulate matter, volatile substances, and gasses. Van et al. (2011) stated that fresh undiluted cigarette smoke contains numerous potentially toxic nanoparticles of which particle size is less than 50 nm.

2.3 Environmental Tobacco Smoke

Tobacco smoke is a mixture of chemicals and gaseous compounds containing about 4800 gaseous and identified particulate mixture. (Baker,1999; Perfetti and Rodgman, 2008). Various health problems could be related with airborne particulate matter (PM). Environmental tobacco smoke (ETS) is one of the most essential anthropogenic pollution in indoor surroundings. Besides, cigarette smoke is a compound of several well-known pollutant gaseous, for instance, carbon monoxide, sulphur dioxide, nitric oxide, nitrogen dioxide, methane, non-methane hydrocarbon, carbonyls, volatile organic compounds, and particulate matter (Diapouli et al., 2011;Wang et al., 2012).

There are two main routes of cigarette smoke generation. One is called mainstream of cigarette smoke (MCS), which is inhaled into the mouth passing through the filter of cigarette. The other one is called sidestream, which is releasing smoke into the air from the burning end. During the tests, sidestream of cigarette smoke was used to evaluate smoke penetration through the respirator.

2.4 Health Effects of Ultrafine Smoke Particles

Fine particulate matters in tobacco smoke and air pollution have significant effects on human mortality. Recent studies state that fine particulates have significant effects especially, on the brain and central nervous system. Fine particulate matters can cause cancer and minimize mortality ages easily. A large amount of studies demonstrated that on average, 60% to 80 % of the mainstream cigarette smoke particulate matter is maintained in the lungs after inhalation. For instance, for nicotine, carbon monoxide, nitric oxide, and aldehydes the total smoke particulate matters retentions are of the order of 90%-100%, 55%-65%, 100%, and approximately 90%, respectively in the lungs after cigarette inhalation. (Baker, & Dixon, 2005).

2.5 P-100 Filter Efficiency Against Nanoparticles

According to the National Institute for Occupational Safety and Health (NIOSH) respirator certification test, a P-100 filter must provide not less than 99.97% efficiency challenged to polydisperse dioctyl phthalate (DOP) particles those having a count median diameter (CMD) of 185 ± 20 nm (Shaffer and Rengasamy, 2009). However, nanoparticle (<100 nm size) exposure in this study is our main concern due to the potential danger on human health. NIOSH approved particulate respirators requirements and suggested to preserve employees against nanoparticles. (Rengasamy and Eimer ,2011).

2.6 Filter Efficiency and Faceseal Leakage

Some studies have been led to determine the filter efficiency of commercially available respirators. Nevertheless, the respirator performance is affected by the filter efficiency, as well as by the faceseal leakage. Additionally, some studies have shown that particle penetration through the faceseal leakage may be higher than through the filter medium (Coffey et al., 1998)

Oestentad and Perkins (1992) stated that respirator leakage was significantly caused by particle leaks at nose and chin areas. Furthermore, similar studies which are related with testing half mask respirator on breathing manikin, concluded that nose area was the primary leak site. (He et al., 2013)

2.7 Flow Types and Rates

It is more complex to quantify the particle penetration under actual breathing conditions, for instance, when the air flow through a respirator is not constant but has a cyclic nature. Early researches marked the effects of faceseal leakage on the particle penetration. (Hinds and Kraske, 1987; Chen et al., 1990; Chen and Willeke, 1992).

There is information deficiency about faceseal cigarette smoke aerosol penetration under the cyclic mean inflammatory flow types. Therefore, it would be crucial to investigate cigarette smoke aerosol penetration under cyclic flow types. Some studies pointed out that artificially fixed leaks and constant flow are not characteristic of actual environmental conditions. To overcome this limitation, not only testing constant, but also cyclic flow was performed under sealed and non-sealed conditions. In this study, sealing material was applied on breathing manikin due to hardships and inconvenience to test human subjects.

2.8 Aerosol Type

Most of the previous researches have used ambient aerosols or nebulizer-generated NaCl to investigate the performance of respirators. In addition, various challenge aerosols, for instance, biological and non-biological, have been used for different respiratory protection research including NaCl, Ag, DOP, and viruses (all including significant number of ultrafine components). Some of the scientists used polystyrene latex spheres as an aerosol in their research (Myers et al.,1991; Quian et al., 1998). Others used fungal spores, bacteria, or viruses.

He et all. (2013) used combustion materials such as wood, paper, and plastic to determine effects of faceseal leakage of half or full elastomeric respirators. However, there is no specific study related with examining cigarette smoke aerosol penetration through half mask elastomeric respirator equipped with double P-100 filters. Since, there is no adequate literature on this subject, it was clear that a research gap is still present.

Chapter 3: Research Design and Methods

3.1 Objective of Study

The purpose of this study is to investigate cigarette smoke penetration on half mask elastomeric respirators with double P-100 filters. To imitate real human breathing, constant and cyclic breathing patterns were used with different rates. Previous studies stated that faceseal leakage was a significant factor of concentration difference between inside and outside of the mask. In this research various sealing conditions were tested to find out leakage between manikin face and half mask elastomeric respirator.

One-way ANOVA compiled test results to find out which variable is more significant among others.

3.2 Experimental Set-up

Total airborne particle concentration was monitored inside (C_{in}) and outside (C_{out}) of the respirator mask. Total penetration through mask was calculated by (C_{in}/C_{out}). Experimental setup is plotted schematically in Figure 3.

An elastomeric half mask respirator with double P-100 filters was donned on manikin's head, and tygon plastic tubes were used to get samples from inside and outside of the mask.

Plastic tygon tubes were attached to the manikin's head to measure outside concentration. Another plastic tube was attached to manikin's neck, and there is connection through to its front face to ensure taking samples from inside of the respirators.

Manikin's head has 1.0-inch diameter copper tube that connects to the neck with breathing simulator. Constant flowing rates were produced by vacuum source of the laboratory and a vacuum pump. Cigarette smoke concentration was measured by TSI P-Trak ultrafine particle counter 8525 (which can count particle size 10 to 1000 nm) in 1-minute intervals with inside and outside of the respirator.

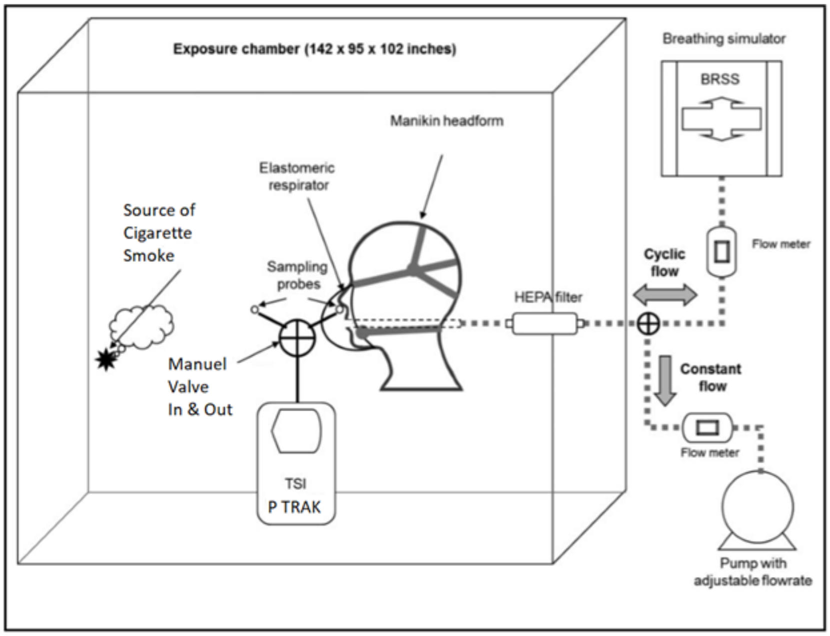

Figure 3: Experimental setup (Modified from He et all.,2013)

3.3 Manikin Set-up

In this study manikin head was donned with medium size 3M 6200 elastomeric half mask respirator with double P-100 filters. As shown in Figure 3, the manikin's head has two holes. One hole, 1-inch diameter, represents an artificial leak from either mouth or nose of the manikin. The other hole, 0.3-inch diameter, will be used to place a sampling probe to measure particle concentration inside of the mask. To mimic breathing condition, the breathing simulator is attached with HEPA filter.

3.3.1 Non-Sealed Test Set-up

Non-sealed tests were conducted for 4 cyclic and 4 constant total 8 breathing types. Measurement of the sampling revealed that faceseal leakage was very significant for this type of test.

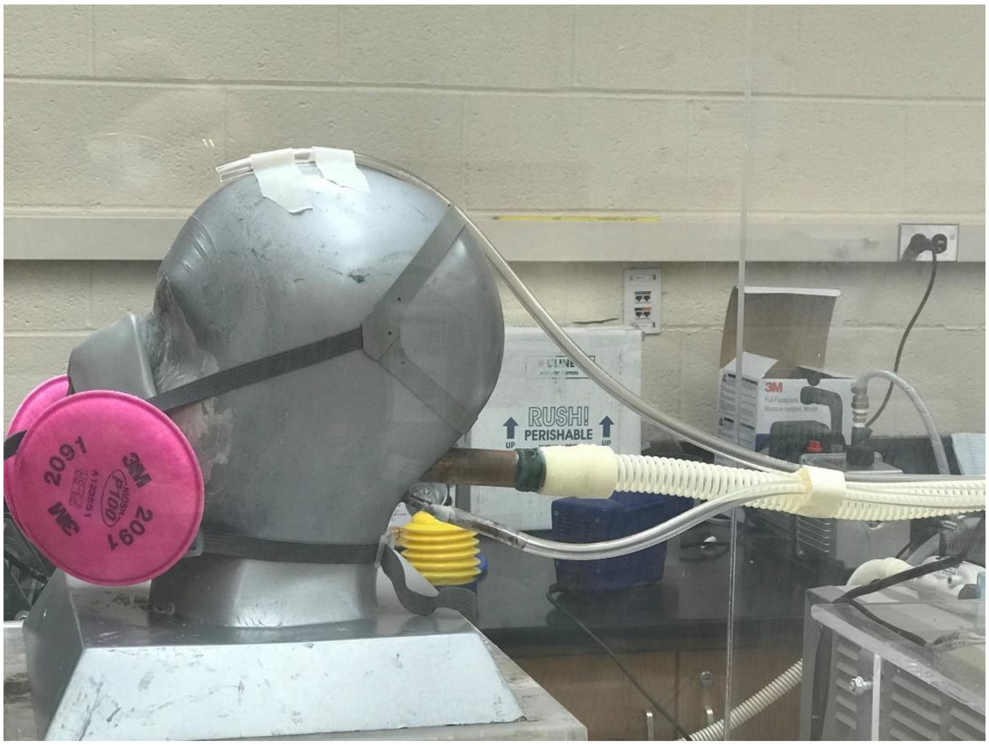

Figure 4: Non-sealed test set-up

As we can see in the figure 4, medium size 3M 6200 half mask respirator with double P 100 filters donned on breathing manikin. This non-sealed condition was tested for 4 cyclic and 4 constant total 8 flowing rates. Each test result was transferred to the spread sheets from particle counter device which is P-Trak.

3.3.2 Only Nose Area Sealed Test Set-up

Silicone sealing material was applied on the breathing manikin to utilize sealing condition tests. Nose area of the breathing manikin was covered with silicone material as seen in Figure 5. Only nose area sealed tests were performed both constant and cyclic types of breathing patterns.

Total 8 different levels of inspiratory flow rates were applied for each breathing type. Sampling was conducted by P- Trak condensation particle counter device. Inside and outside of the respirator concentration was measured by sampling device every minute during the test.

Figure 5: Only nose sealed test set up and sealing silicone

3.3.3 Nose and Chin Areas Sealed Test Set-up

Silicone sealing material was applied on breathing manikin’s face to determine sealing condition of the test. Nose and chin areas of the breathing manikin were covered with silicone material as seen in Figure 6. Nose and chin areas sealed tests were performed both constant and cyclic types of breathing pattern. Total 4 different levels of inspiratory flow rates were applied for each breathing type. Sampling was measured from the inside and outside of the respirator’s measurement terminals by P- Trak condensation particle counter device. Inside and outside of the respirator concentration was measured by sampling device each minute during the test.

Figure 6: Nose and chin areas sealed test set-up

3.3.4 Fully-Sealed Test Set-up

Nose, chin and chick areas of the breathing manikin were covered with silicone material as seen in Figure 7. Fully-sealed tests were performed both constant and cyclic types of breathing patterns. Total 4 different levels of inspiratory flow rates were applied for each breathing type. Sampling was measured from inside and outside of the measurement terminals by P- Trak condensation particle counter device. Inside and outside of the respirator concentration were measured by sampling device each minute during the test.

Figure 7: Fully sealed test set-up

3.4 Smoke Generation

Unfortunately, there was no smoke generation device to produce smoke aerosol with different concentration levels in the laboratory. Therefore, cigarette was used to generate combustion smoke source in the testing chamber. While generating combustion smoke, keeping constant concentration levels of smoke could not be satisfying, therefore, after burning a cigarette, sampling was started when the outside concentration levels reached up to maximum measurable value of the sampling device. Maximum sampling concentration is 500000 particle per cubic centimeter for the P-Trak.

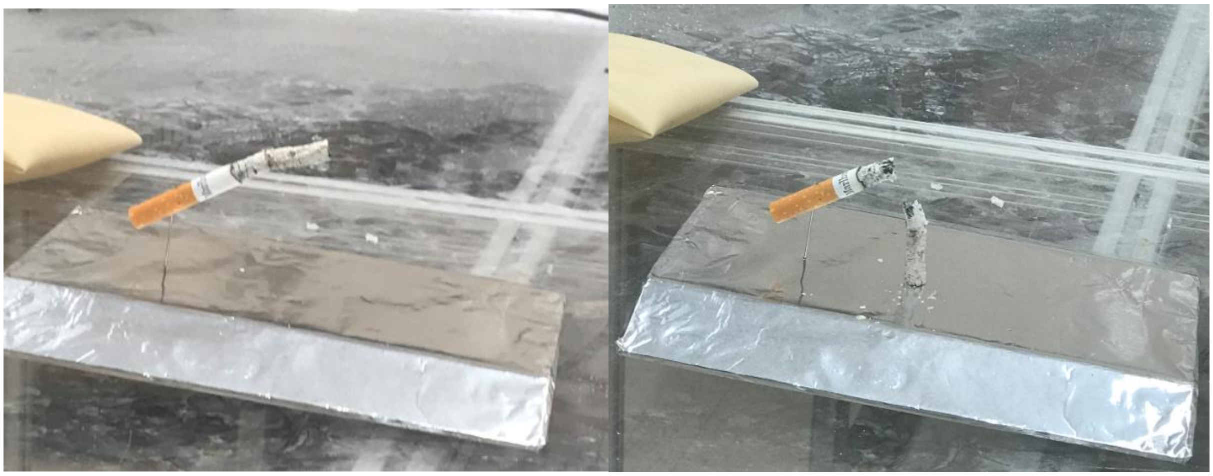

Figure 8: Combustion cigarette smoke generator

3.5 Instrumentation

In this study P-Trak ultrafine particle counter 8525 was used to measure particle concentration in the experimental chamber and inside of the elastomeric half mask respirator. P-Trak ultrafine particle counter is commonly used to monitor ultrafine particles in helping elimination of indoor air quality problems. Considering the fact that it is difficult to adjust smoke aerosol concentration levels, the whole sampling process plotted decaying smoke concentration trends. The inside and outside concentration levels were sampled by P–Trak ultrafine particle counter device in every minute. Since, we have only one instrument, particle concentrations inside and outside the respirator cannot be measured simultaneously. Thus, a manual value was used to switch the measurement between inside and outside of the respirator.

Figure 9: TSI P-Trak ultrafine particle counter 8525 (TSI Incorporated, 2013)

3.6 Test Conditions

In this experiment, a medium size 3M 6200 half mask respirator with double P-100 filters was tested. Constant and cyclic breathing patterns were used to simulate human breathing features closely. Manikin Breathing Rate was changed between cyclic and constant with the values of (15, 30, 50, and 85 L/min).

Similar studies pointed out that common leakage places are nose, chin, and cheek areas. In this study 4 sealing types such as, non-sealed, only nose sealed, nose and chin sealed, and fully sealed conditions were tested. Each sealing condition was established by applying a silicone material between the manikin’s face and the respirator, every test was replicated 3 times.

Table 1: Experimental Conditions

Variable	Levels
Respirator type	3M 6200 Half mask
Sealing condition	4 (unsealed, only nose sealed, nose and chin sealed, fully sealed)

Burning material	A cigarette
Manikin breathing rate	4 cyclic (15, 30, 50, 85 L/min) 4 constants (15, 30, 50, 80 L/min)
Replicates	3
Total runs	1x4x8x3=96

3.7 Testing Procedure

Each test condition was conducted as follows:

1. P-Trak was turned on;
2. P- Trak automatically counted down to 60 seconds in order to get ready for sampling;
3. Storage cap was removed and alcohol cartridge was inserted;
4. A zero-calibration filter was connected to the inlet screen assembly to utilize pre-calibration;
5. Zero calibration filter was removed;
6. Tygon plastic tubing was attached to inlet screen assembly to measure the outside concentration;
7. A cigarette was burnt with a lighter in the testing chamber;
8. P- Trak was set to operate in data logging mode;
9. P- Trak was set to sample 60 seconds intervals;
10. P-Trak's display was monitored until the maximum particle concentration on the screen reached to 500000 pt/cc;
11. After reading the outside maximum concentration, sampling tubes were switched from inside to outside to measure inside and outside concentration every minute.

Aerosol generation was not under control, especially concentration of smoke cannot be adjusted on certain points, therefore, decaying type of aerosol concentration was plotted in this study.

All sampled data were saved into P-Trak memory. Connection cable was used to connect P-Trak to computer in order to transfer sampling data to the computer.

Alcohol wick was soaked into alcohol and allowed to insert P-Trak before starting every new sampling. Four small ventilation devices were used to maintain homogenous environment into the testing chamber.

3.8 Data Collection

Data collection was performed completely in randomized testing order. All tests were repeated 3 times. While collecting samples, P-Trak particle counter was running in a log mode and saved the number of sampled particle concentration in its memory. Sampler was set for one-minute data logging interval.

Combustion smoke aerosol generation was not under control; therefore, concentration of smoke could not be adjusted on certain levels. Thus, concentration levels could not be used as a variable to find out whether it was or was not significant feature of effecting penetration on the half mask. A cigarette was burnt in the testing chamber and sampling was not started until concentration level reached up to sampler device maximum measurement point which is 500000 pt/cc.

3.9 Data Analysis

For each combination of experimental conditions, the mean value of triplicated runs and the standard deviation were calculated. There were 4 types of sealing, 2 types of breathing flow, 4 types of flowing rates for each breathing type, and 3 replicates of testing produced total 96 tests.

In this study, our null hypothesis claimed that flowing rates, breathing and sealing types have no significant effects on the total penetration of ultrafine cigarette smoke aerosol through 3M 6200 half mask respirator equipped with P-100 filters. In order to evaluate null hypothesis, one-way analysis of variance (ANOVA) was conducted to quantify the effects of sealing condition, flowing rates, and flowing types on the particle penetration separately.

Chapter 4: Results

4.1. Effects of Sealing on Total Penetration

The null hypothesis states that sealing types have no significant effects on total cigarette smoke penetration through 3M-6200 half mask with P-100 filters. In contrast, the alternative hypothesis would be defined as sealing types have significant effects on penetration percentages through the half mask respirator with P-100 filters. In order to provide acceptable evidence to prove this alternative hypothesis statistically, ANOVA one-way analysis of variance was conducted to quantify the effects of sealing condition on the particle penetration through the half mask. Mean values of penetration percentages were measured from all 3 replicate tests. A summary of the test results is demonstrated in Table 2.

Table 2: Mean values of penetration percentages from 3 replicates

		Penetration, % (Mean±STD)			
Flow Type	Flow Rate	Non sealed	Nose only sealed	nose and chin sealed	fully sealed
CONSTANT	CONSTANT 15LPM	84.45 ± 1.57	11.17 ± 2.01	0.235 ± 0.0044	0.0040 ± 0.00089
	CONSTANT 30LPM	78.52 ± 3.66	3.33 ± 0.63	0.327 ± 0.0032	0.0011 ± 0.00026
	CONSTANT 50LPM	70.86 ± 2.49	6.42 ± 1.61	0.357 ± 0.0023	0.0039 ± 0.00063
	CONSTANT 80LPM	72.88 ± 3.00	8.72 ± 2.06	0.702 ± 0.0607	0.0030 ± 0.00045
CYCLIC	CYCLIC 15LPM	87.53 ± 3.69	18.40 ± 2.02	0.046 ± 0.0033	0.0286 ± 0.00042
	CYCLIC 30LPM	80.58 ± 0.77	5.81 ± 1.38	0.036 ± 0.0007	0.0321 ± 0.00091
	CYCLIC 50LPM	56.70 ± 5.55	9.58 ± 2.15	0.056 ± 0.0134	0.0299 ± 0.00141
	CYCLIC 85LPM	54.28 ± 3.45	4.17 ± 0.94	0.170 ± 0.0542	0.0231 ± 0.00033

4.1.1 Analyzing the Effects of Sealing Types on Total Penetration

While analyzing the effects of different sealing types on total penetration, single factor ANOVA test was conducted statistically to calculate P- value. The null hypothesis states that sealing has no significant effects on ultrafine cigarette smoke penetration through half mask respirator with P-100 filters. Alpha value was assigned as $\alpha=0.05$ to detect statistically significant difference.

If the analysis rendered P< α, then we would reject the null hypothesis. Table 3 describes the results of one-way ANOVA statistical analysis. The results show that P= 7.58 E-20< α, therefore, we could reject the null hypothesis. Hence, sealing types have significant effects on penetration percentages of the half mask respirator with P-100 filters.

Table 3: One-way ANOVA test result to the determine effects of sealing types

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Non sealed	8	585.8086	73.22607	150.0662
Nose only sealed	8	67.60718	8.450897	23.32833
nose and chin sealed	8	1.927717	0.240965	0.050421
fully sealed	8	0.12578	0.015722	0.000193

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30042.02	3	10014.01	230.9435	7.58E-20	2.946685
Within Groups	1214.116	28	43.36129			
Total	31256.14	31				

4.1.2 Error Bars of Non-Sealed Half Mask

For the constant flow type, the percent penetration ranged from 71% to 85% for all testing flow rates, while the cyclic flow type showed the percent penetration ranging from 55% to 88%. Among all test conditions, the lowest penetration was observed when tested at a cyclic flow rate of 85 L/min, while the highest penetration happened at a cyclic flow rate of 15 L/min. Penetration percentages were recorded relatively high when compared to sealed condition test.

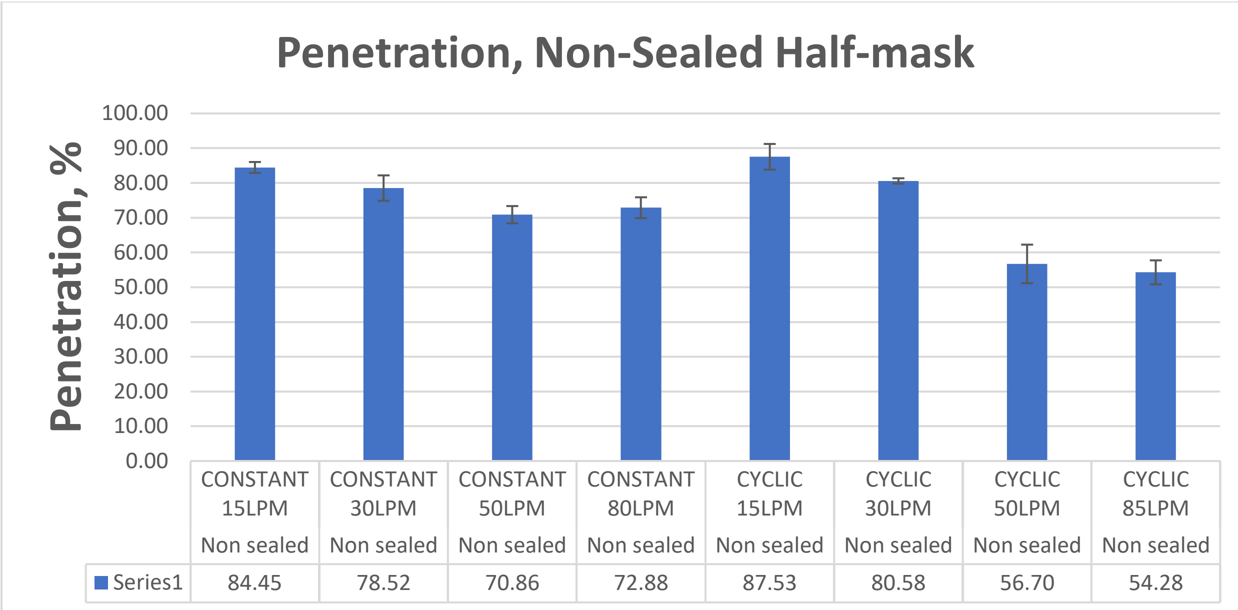

Figure 10: Error bars for non-sealed half mask test set-up

4.1.3 Error Bars of Only Nose Sealed Half Mask

As shown in Figure 11, penetration percentages were derived from the mean value of 3 test replicates of each testing combination. The measurement of maximum penetration percentage which was 18.40%, was recorded at cyclic flow of 15 L/min test. In addition, the minimum measurement of penetration percentage which was 3.34%, was calculated at constant flow of 30 L/min test. When the penetration percentages of only nose area sealed were compared with those of non-sealed tests, the penetration percentages for all flow rates were much smaller than those of the non-sealed condition test, clearly indicating that faceseal leakage was relatively high in non-sealed condition.

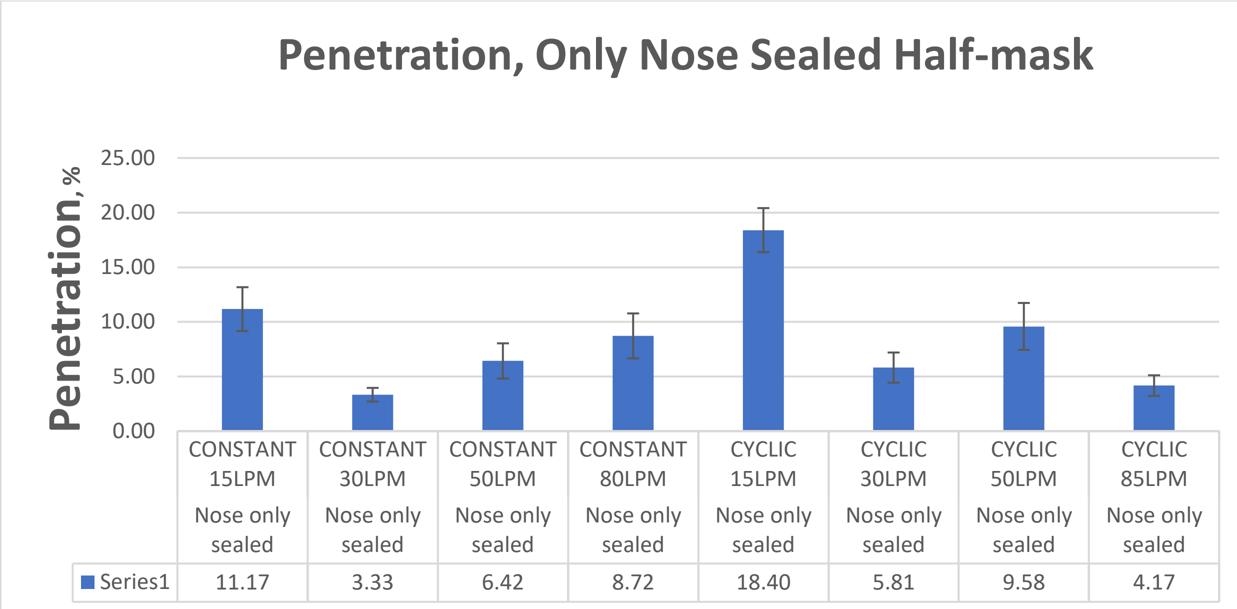

Figure 11: Error bars for nose only sealed test set-up

4.1.4 Error Bars of Nose and Chin Sealed Half Mask

As shown in Figure 12, penetration percentages were lower than non-sealed and only nose sealed test results. However, the mean value of penetration percentages was still higher than an acceptable filter performance percentage 0.03%.

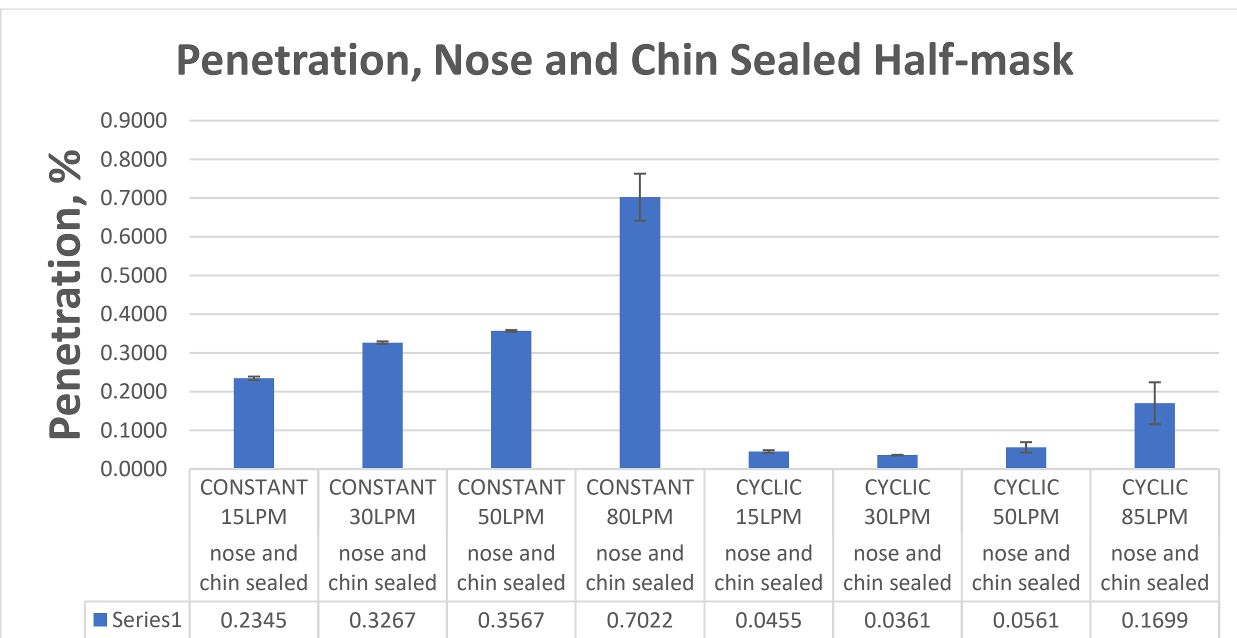

Figure 12: Error bars for nose and chin sealed test set-up

4.1.5 Error Bars of Fully Sealed Half Mask

Fully sealed half mask test results showed that the constant flow types and rates were within the acceptable penetration percentage value (0.03%). In contrast, the cyclic flow type had higher percentage values, especially a cyclic flow rate of 30 L/min showed 0.032% penetration value and exceeded the acceptable value.

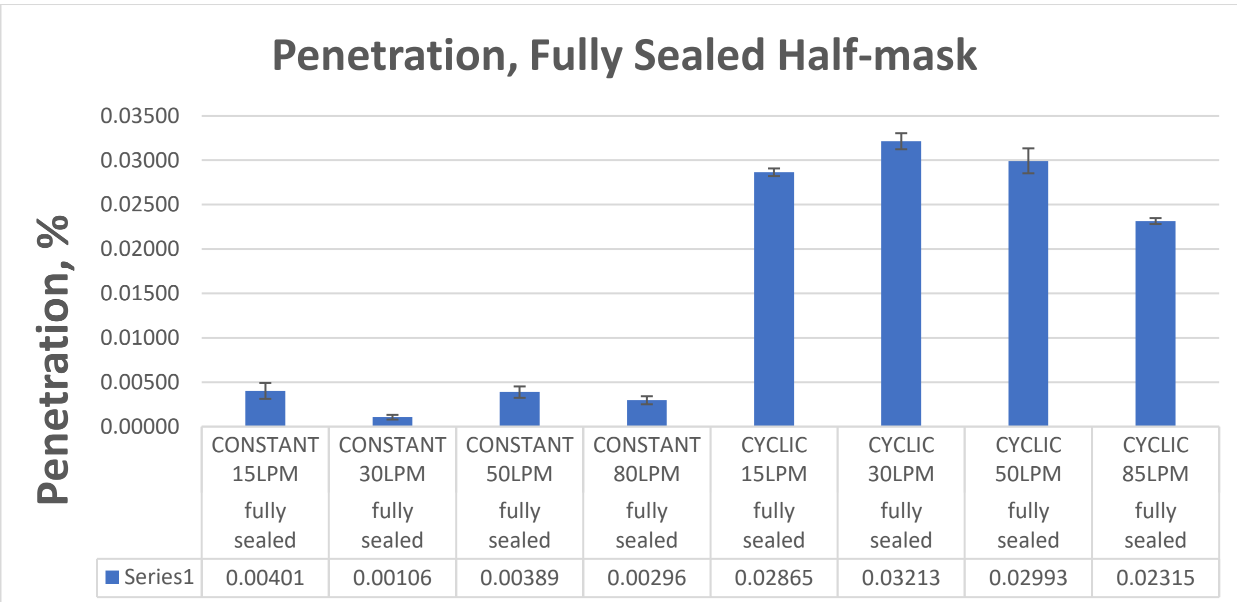

Figure 13: Error bars for fully sealed test set-up

4.2 Effects of Flow Rate on Total Penetration

In order to evaluate the effects of flow rates on total penetration, single factor ANOVA test was performed statistically to calculate P value. The null hypothesis states that flow rate has no significant effects on ultrafine cigarette smoke penetration through the half mask respirator with P-100 filters. Alpha value was assigned as $\alpha=0.05$, P value for flow rate was calculated by single way variance of ANOVA statistically.

The effects of flow rate on total penetration was investigated for each sealing types separately. If we take into consideration of only one sealing type, we could measure the effects of different flow rates effects on cigarette smoke penetration through half mask for each sealing types.

4.2.1 Effects of Flow Rates on Total Penetration for Non-Sealed Test Results

The effects of flow rates on total cigarette smoke penetration were investigated for non-sealed test conditions. For the statistical analysis, sealing was considered as a fixed variable.

The null hypothesis claims that flow rate has no significant effects on ultrafine cigarette smoke penetration through the half mask respirator for non-sealed tests condition. Table 4 describes the results of single way variance of ANOVA statistical analysis. The results express that P= 6.69511E-42<α, therefore, we would reject the null hypothesis. Hence, flow rate has significant effects on penetration percentages of the half mask respirator with P-100 filter for non-sealed condition.

Table 4: Effects of flow rates on total penetration for non-sealed tests

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Non-Sealed Constant 15LPM	17	1435.679	84.45172	26.81231
Non-Sealed Constant 30LPM	23	1805.991	78.52136	23.99074
Non-Sealed Constant 50LPM	16	1133.824	70.86399	93.68719
Non-Sealed Constant 80LPM	19	1384.7	72.87892	29.51294
Non-Sealed Cyclic 15LPM	23	2013.158	87.5286	22.03907
Non-Sealed Cyclic 30LPM	13	1047.576	80.58281	35.40228
Non-Sealed Cyclic 50LPM	23	1304.128	56.70122	29.74656
Non-Sealed Cyclic 85LPM	12	651.3599	54.28	85.0889

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18825.36	7	2689.337	68.81131	6.69511E-42	2.076559
Within Groups	5393.423	138	39.08278			
Total	24218.78	145				

4.2.2 Effects of Flow Rates on Total Penetration for Only Nose Sealed Test Results

For only nose sealed tests, we have the same null hypothesis. Table 5 shows the results of single way variance of ANOVA statistical analysis. The results demonstrate that P= 6.0787E-51<α, therefore, we would reject the null hypothesis. For this reason, flow rate has significant effects on penetration percentages of the half mask respirator with P-100 filter for only nose sealed condition.

Table 5: Effects of flow rates on total penetration for only nose sealed tests

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Nose Sealed Constant 15LPM	30	370.0767	12.33589	20.13738
Nose Sealed Constant 30LPM	25	83.31431	3.332572	5.831721
Nose Sealed Constant 50LPM	22	141.3255	6.423887	4.228294
Nose Sealed Constant 80LPM	18	156.891	8.716169	4.800371
Nose Sealed Cyclic 15LPM	31	570.3756	18.39921	9.099042
Nose Sealed Cyclic 30LPM	29	168.6055	5.813983	12.51619
Nose Sealed Cyclic 50LPM	30	287.5121	9.583738	10.99058
Nose Sealed Cyclic 85LPM	25	104.2328	4.169312	6.894244

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4910.692	7	701.5274	70.78493	6.07874E-51	2.055134
Within Groups	2001.959	202	9.910689			
Total	6912.651	209				

4.2.3 Effects of Flow Rates on Total Penetration for Nose and Chin Sealed Test Results

Table 6 indicates the results of single way variance of ANOVA statistical analysis for determining effects of flow rates on total penetration for nose and chin areas sealed tests. The results exhibit that P= 1.62654E-37<α, therefore, we would reject the null hypothesis indicating that flow rate has significant effects on penetration percentages of the half mask respirator with P-100 filter for only nose and chin sealed test.

Table 6: Effects of flow rates on total penetration for nose and chin sealed tests

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Nose & Chin Sealed Constant 15LPM	15	3.517796	0.23452	0.007307
Nose & Chin Sealed Constant 30LPM	16	5.227252	0.326703	0.020731
Nose & Chin Sealed Constant 50LPM	17	6.06427	0.356722	0.021718
Nose & Chin Sealed Constant 80LPM	15	10.53305	0.702203	0.032281
Nose & Chin Sealed Cyclic 15LPM	17	0.773729	0.045513	0.005661
Nose & Chin Sealed Cyclic 30LPM	15	0.541504	0.0361	0.001459
Nose & Chin Sealed Cyclic 50LPM	16	0.896846	0.056053	0.000416
Nose & Chin Sealed Cyclic 85LPM	13	2.208736	0.169903	0.002669

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.428726	7	0.775532	66.05335	1.62654E-37	2.089477
Within Groups	1.361956	116	0.011741			
Total	6.790682	123				

4.2.4 Effects of Flow Rates on Total Penetration for Fully Sealed Test Results

Table 7 demonstrates the results of single way variance of ANOVA statistical analysis for investigating effects of flow rates on total penetration for fully sealed tests. The results establish that P= 1.32642E-15<α, therefore, we would reject the null hypothesis. P value concludes that flow rate has significant effects on penetration percentages of the half mask respirator with P-100 filter for fully sealed test.

Table 7: Effects of flow rates on total penetration for fully-sealed tests

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Fully-Sealed Constant 15LPM	18	0.072257	0.004014	1E-05
Fully-Sealed Constant 30LPM	16	0.016973	0.001061	5.05E-07
Fully-Sealed Constant 50LPM	14	0.054461	0.00389	5.69E-05
Fully-Sealed Constant 80LPM	12	0.035493	0.002958	3.23E-06
Fully-Sealed Cyclic 15LPM	27	0.773483	0.028648	0.000652
Fully-Sealed Cyclic 30LPM	24	0.771205	0.032134	8.56E-05
Fully-Sealed Cyclic 50LPM	24	0.71823	0.029926	4.69E-05
Fully-Sealed Cyclic 85LPM	20	0.462988	0.023149	0.000637

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.025328	7	0.003618	16.09249	1.32642E-15	2.072404
Within Groups	0.033052	147	0.000225			
Total	0.05838	154				

4.3 Effects of Flow Type on Total Penetration

The null hypothesis is that flow type has no significant effects on ultrafine cigarette smoke penetration through the half mask respirator.

Single way variance of ANOVA statistical analysis was performed for each sealing and flow rate conditions. We have 4 sealing types and 4 flow rates which produce total 16 combinations. Each sealing type and flow rate was tested in order to find out whether flow type has any significant effects on total penetration through the half mask respirator with P-100 filters or not.

4.3.1 Effects of Flow Types on Total Penetration for Non-Sealed Test Results

4.3.1.1 15 LPM flow rate

Table 8 indicates that flow type does not have statistically significant effects on total penetration for non-sealed, 15 LPM (Liter per minute) test ($P=0.05716 > 0.05$). This means we would fail to reject the null hypotheses.

Table 8: Flow types on total penetration for non-sealed respirator (15 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Non-Sealed **Constant** 15LPM	17	1435.679	84.45172	26.81231
Non-Sealed **Cyclic** 15LPM	23	2013.158	87.5286	22.03907

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	92.54178	1	92.54178	3.848074	**0.057159455**	4.098172
Within Groups	913.8565	38	24.04886			
Total	1006.398	39				

4.3.1.2 30 LPM flow rate

Table 9 expresses that flow types have no significant effects on the total penetration for non-sealed, 30 LPM (Liter per minute) test ($P=0.2696 > 0.05$). This means we would fail to reject the null hypotheses.

Table 9: Effects of flow types on total penetration for non-sealed respirator (30 LPM)

SUMMARY

Groups	Count	Sum	Average	Variance
Non-Sealed **Constant** 30LPM	23	1805.991	78.52136	23.99074
Non-Sealed **Cyclic** 30LPM	13	1047.576	80.58281	35.40228

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	35.29506	1	35.29506	1.259713	0.269569221	4.130018
Within Groups	952.6236	34	28.01834			
Total	987.9187	35				

4.3.1.3 50 LPM flow rate

Table 10 demonstrates that the flow types which are constant and cyclic have significant effects on total penetration for non-sealed, 50 LPM (Liter per minute) test (P=1.064E-06< 0.05). This means we would reject the null hypotheses. The constant flow rate showed higher average percent than cyclic flow rate (71% vs. 57%) when the comparison was made at 50 LPM.

Table 10: Effects of flow types on total penetration for non-sealed respirator (50 LPM)

SUMMARY

Groups	Count	Sum	Average	Variance
Non-Sealed **Constant** 50LPM	16	1133.824	70.86399	93.68719
Non-Sealed **Cyclic** 50LPM	23	1304.128	56.70122	29.74656

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1892.691	1	1892.691	33.99935	1.06394E-06	4.105456
Within Groups	2059.732	37	55.66844			
Total	3952.423	38				

4.3.1.4 80 and 85 LPM flow rate

Table 11 exhibits that flow types which are constant and cyclic have significant effects on total penetration for non-sealed, constant 80 and cyclic 85 LPM (Liter per minute) tests (P=8.404E-08< 0.05). Therefore, we would reject the null hypotheses.

Table 11: Effects of flow types on total penetration for non-sealed respirator (80 and 85 LPM)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Non-Sealed **Constant** 80LPM	19	1384.7	72.87892	29.51294
Non-Sealed **Cyclic** 85LPM	12	651.3599	54.28	85.0889

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2544.187	1	2544.187	50.28685	8.40368E-08	4.182964
Within Groups	1467.211	29	50.59348			
Total	4011.397	30				

4.3.2 Effects of Flow Types on Total Penetration for Only Nose Sealed Test Results

4.3.2.1 15 LPM flow rate

Table 12 shows that flow types which are constant and cyclic have significant effects on total penetration for only nose sealed, 15 LPM (Liter per minute) test ($P=5.7358E\text{-}08 < 0.05$). This means we would reject the null hypotheses.

Table 12: Effects of flow types on total penetration for only nose sealed respirator (15 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Nose Sealed **Constant** 15LPM	30	370.0767	12.33589	20.13738
Nose Sealed **Cyclic** 15LPM	31	570.3756	18.39921	9.099042

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	560.4991	1	560.4991	38.58946	5.73581E-08	4.003983
Within Groups	856.9554	59	14.52467			
Total	1417.454	60				

4.3.2.2 30 LPM flow rate

Table 13 indicates constant and cyclic flow types which have significant effects on total penetration for non-sealed, 30 LPM (Liter per minute) test ($P=0.0046 < 0.05$). This means we could reject the null hypotheses.

Table 13: Effects of flow types on total penetration for only nose sealed respirator (30 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Nose Sealed **Constant** 30LPM	25	83.31431	3.332572	5.831721
Nose Sealed **Cyclic** 30LPM	29	168.6055	5.813983	12.51619

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	82.66879	1	82.66879	8.765595	0.004615995	4.026631
Within Groups	490.4147	52	9.431052			
Total	573.0835	53				

4.3.2.3 50 LPM flow rate

The comparison of penetration between constant and cyclic flow rates showed a statistically significant difference ($P=0.00025 < 0.05$), showing higher percent penetration for the cyclic flow rate than for the constant flow rate. This means we could reject the null hypotheses.

Table 14: Effects of flow types on total penetration for only nose sealed respirator (50 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Nose Sealed **Constant** 50LPM	22	141.3255	6.423887	4.228294
Nose Sealed **Cyclic** 50LPM	30	287.5121	9.583738	10.99058

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	126.7284	1	126.7284	15.5487	0.000250705	4.03431
Within Groups	407.5209	50	8.150418			
Total	534.2492	51				

4.3.2.4 80 and 85 LPM flow rate

The comparison of penetration between constant and cyclic flow rates showed a statistically significant difference (P=4.4425E-07< 0.05), showing higher percent penetration for the constant flow rate than for the cyclic flow rate. This means we could reject the null hypotheses.

Table 15: Effects of flow types on total penetration for only nose sealed respirator (80 and 85 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Nose Sealed **Constant** 80LPM	18	156.891	8.716169	4.800371
Nose Sealed **Cyclic** 85LPM	25	104.2328	4.169312	6.894244

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	216.3548	1	216.3548	35.90324	4.4425E-07	4.078546
Within Groups	247.0682	41	6.026053			
Total	463.423	42				

4.3.3 Effects of Flow Types on Total Penetration for Nose and Chin Sealed Test Results

4.3.3.1 15 LPM flow rate

Table 16 demonstrates that the flow types which are constant and cyclic have significant effects on total penetration for nose and chin sealed test (P=2.2749E-07< 0.05). For that reason, we could reject the null hypotheses.

Table 16: Effects of flow types on total penetration for nose and chin sealed respirator (15 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Nose & Chin Sealed **Constant** 15LPM	15	3.517796	0.23452	0.007307
Nose & Chin Sealed **Cyclic** 15LPM	17	0.773729	0.045513	0.005661

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.284671	1	0.284671	44.28105	2.27489E-07	4.170877
Within Groups	0.192862	30	0.006429			
Total	0.477532	31				

4.3.3.2 30 LPM flow rate

As shown in Table 17, flow rates (constant and cyclic) have significant effects on total penetration for nose and chin sealed test (P=2.44E-08< 0.05). When compared at 30 LPM, the constant flow rate showed higher average percent than the cyclic flow rate (0.3% vs. 0.03%). This means we could reject the null hypotheses.

Table 17: Effects of flow types on total penetration for nose and chin sealed respirator (30 LPM)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Nose & Chin Sealed **Constant** 30LPM	16	5.227252	0.326703	0.020731
Nose & Chin Sealed **Cyclic** 30LPM	15	0.541504	0.0361	0.001459

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.653807	1	0.653807	57.2132	2.44421E-08	4.182964
Within Groups	0.331399	29	0.011428			
Total	0.985206	30				

4.3.3.3 50 LPM flow rate

Table 18 shows that flow rates which are constant and cyclic, have significant effects on total penetration for nose and chin sealed test (P=3.99E-09< 0.05), which means we could reject the null hypotheses for this type of test.

Table 18: Effects of flow types on total penetration for nose and chin sealed respirator (50 LPM)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Nose & Chin Sealed **Constant** 50LPM	17	6.06427	0.356722	0.021718
Nose & Chin Sealed **Cyclic** 50LPM	16	0.896846	0.056053	0.000416

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.74513	1	0.74513	65.30096	3.98928E-09	4.159615
Within Groups	0.353732	31	0.011411			
Total	1.098862	32				

4.3.3.4 80 and 85 LPM flow rates

As seen in Table 19, constant and cyclic flow rates have significant effects on total penetration for nose and chin sealed test when compared at 80 and 85 LPM (P=1.15E-10< 0.05). This means we could reject the null hypotheses.

Table 19: Effects of flow types on total penetration for nose and chin sealed respirator (80 and 85 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Nose & Chin Sealed **Constant** 80LPM	15	10.53305	0.702203	0.032281
Nose & Chin Sealed **Cyclic** 85LPM	13	2.208736	0.169903	0.002669

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.973286	1	1.973286	106.011	1.15053E-10	4.225201
Within Groups	0.483963	26	0.018614			
Total	2.457249	27				

4.3.4 Effects of Flow Types on Total Penetration for Fully Sealed Test Results

4.3.4.1 15 LPM flow rate

Table 20 demonstrates that P value is lower than alpha (P=0.00020< 0.05) for fully sealed test. Cyclic flow rate shows a higher average percent than constant flow rate (0.7% vs. 0.07%) when compared at 15 LPM. This means we could reject the null hypotheses.

Table 20: Effects of flow types on total penetration for fully sealed respirator (15 LPM)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Fully-Sealed **Constant** 15LPM	18	0.072257	0.004014	1E-05
Fully-Sealed **Cyclic** 15LPM	27	0.773483	0.028648	0.000652

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.006553	1	0.006553	16.46124	0.000205445	4.067047
Within Groups	0.017119	43	0.000398			
Total	0.023672	44				

4.3.4.2 30 LPM flow rate

Table 21 shows that flow rates have significant effects on total penetration for fully sealed test (P=6.36E-16< 0.05). The cyclic flow rate shows a higher average percent than the constant flow rate (0.7% vs. 0.01%) when comparison was made at 30 LPM, which means we could reject the null hypotheses.

Table 21: Effects of flow types on total penetration for fully sealed respirator (30 LPM)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Fully-Sealed **Constant** 30LPM	16	0.016973	0.001061	5.05E-07
Fully-Sealed **Cyclic** 30LPM	24	0.771205	0.032134	8.56E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.009269	1	0.009269	178.1815	6.35651E-16	4.098172
Within Groups	0.001977	38	5.2E-05			
Total	0.011246	39				

4.3.4.3 50 LPM flow rate

Table 22 demonstrates that flow rates (constant and cyclic) have significant effects on total penetration for fully sealed test when compared at 50 LPM (P=6.035E-13< 0.05). This means we could reject the null hypotheses.

Table 22: Effects of flow types on total penetration for fully sealed respirator (50 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Fully-Sealed **Constant** 50LPM	14	0.054461	0.00389	5.69E-05
Fully-Sealed **Cyclic** 50LPM	24	0.71823	0.029926	4.69E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.005994	1	0.005994	118.6377	6.03506E-13	4.113165
Within Groups	0.001819	36	5.05E-05			
Total	0.007813	37				

4.3.4.4 80 and 85 LPM flow rate

As seen in Table 23, flow rates (constant and cyclic) have significant effects on total penetration for fully sealed test when compared at 80 and 85 LPM (P=0.0100< 0.05). The constant flow rate shows a higher average percent than the cyclic flow rate (0.003% vs. 0.02%). That means we could reject the null hypotheses.

Table 23: Effects of flow types on total penetration for fully sealed respirator (80 and 85 LPM)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Fully-Sealed **Constant** 80LPM	12	0.035493	0.002958	3.23E-06
Fully-Sealed **Cyclic** 85LPM	20	0.462988	0.023149	0.000637

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.003058	1	0.003058	7.557851	0.010020427	4.170877
Within Groups	0.012138	30	0.000405			
Total	0.015195	31				

Chapter 5: Conclusion

The purpose of this study was to evaluate ultrafine cigarette smoke penetration through a 3M 6200 elastomeric half mask respirators with P-100 filters. P-Trak particle counter was utilized to measure number of smoke particles from measurement terminals. In order to investigate our null hypothesis, several testing conditions were planned and applied on the breathing manikin. Statistical tests were performed using One-way ANOVA to determine the most significant variable that affects smoke particle penetration through the half mask respirator.

The statistical test results revealed that overall sealing conditions, flow types, and flow rates have significant effects on cigarette smoke penetration through the half mask respirator. When the penetration was compared between the constant and cyclic flow rates for the non-sealed respirator, no statistically significant differences were detected for 15 and 30 LPM, while other flow rates showed significant differences.

Cigarette smoke penetration through the elastomeric half mask respirator were measured unexpectedly higher percentages. Those exceeded penetration percentages might be observed due to loose fitting of half mask or breathing manikin's hard plastic materials itself. Breathing manikin's head was made of hard plastic which could not represent real human being skin features. Hard plastic production materials might utilize tiny gaps between half mask and plastic material. Therefore, penetration percentages could have been measured relatively higher even for fully sealed tests.

Regardless of these limitations, 3M 6200 half mask respirator with double P-100 filters should have a capability of capturing ultrafine cigarette smoke particles successfully to protect employees from adverse health consequences of ultrafine smoke particles.

In conclusion, cigarette smoke particle penetration through 3M 6200 half mask respirator measured higher than the acceptable threshold value of 0.03%. Especially, a fully sealed respirator testing at 30 LPM showed penetration of $0.032\% > 0.03\%$ (acceptable penetration percent). However, based on our test results, smoke penetration percentages were measured higher than the threshold value even in the partially sealed and fully sealed testing conditions.

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Appendix A:

Non sealed-TEST1				Non sealed-TEST2			Non sealed-TEST3		
Constant flow rate :15L/min				Constant flow rate :15L/min			Constant flow rate :15L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%
1	405995	450730	90.1	385408	446177	86.4	383826	468942	81.8
2	434988	447975	97.1	374079	408356	91.6	392879	488253	80.5
3	413660	472225	87.6	447284	476854	93.8	437456	439818	99.5
4	346683	471876	73.5	394318	481039	82.0	381337	421483	90.5
5	291159	360480	80.8	295875	386765	76.5	270369	379255	71.3
6	219093	306037	71.6	224933	280295	80.2	239953	271716	88.3
7	213578	232701	91.8	188906	225577	83.7	189325	254072	74.5
8	160034	225791	70.9	195670	221609	88.3	179797	193835	92.8
9	139878	218991	63.9	186367	217000	85.9	161258	182564	88.3
10	151382	168862	89.6	175456	199401	88.0	143315	170659	84.0
11	152621	172890	88.3	132903	152621	87.1	127404	197905	64.4
12	141197	144357	97.8	147273	150190	98.1	136113	142900	95.3
13	115462	147867	78.1	122786	146432	83.9	118476	136383	86.9
14	96880	141240	68.6	118927	141240	84.2	113428	113520	99.9
15	93536	117434	79.6	115801	136804	84.6	94118	108960	86.4
16	106132	106418	99.7	84956	100876	84.2	84042	125264	67.1
17	85010	105767	80.4	79059	93794	84.3	83461	99781	83.6
Non sealed-TEST1				Non sealed-TEST2			Non sealed-TEST3		
Constant flow rate: 30L/min				Constant flow rate: 30L/min			Constant flow rate: 30L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%
1	431019	478989	90.0	425691	474151	89.8	441834	498343	88.7
2	361885	466676	77.5	349884	452390	77.3	388391	509534	76.2
3	275952	406164	67.9	285676	422092	67.7	242644	366344	66.2
4	212495	281069	75.6	223728	297442	75.2	175414	240138	73.0
5	173284	204895	84.6	198969	236910	84.0	161447	198493	81.3
6	185127	205475	90.1	156818	174750	89.7	170094	195874	86.8
7	159778	183341	87.1	166802	192695	86.6	154884	185213	83.6
8	161416	194039	83.2	151587	183259	82.7	128431	161700	79.4
9	149115	182914	81.5	144117	177926	81.0	106629	138018	77.3
10	113255	141314	80.1	134642	169878	79.3	105578	139812	75.5
11	101006	124822	80.9	100006	124822	80.1	123734	161859	76.4
12	102102	124382	82.1	96072	118100	81.3	103652	134434	77.1
13	91906	119702	76.8	91774	120864	75.9	76726	108081	71.0
14	86245	108156	79.7	83680	106135	78.8	64875	88952	72.9

15	69052	86526	79.8	71483	90987	78.6	65298	90096	72.5
16	61570	77108	79.8	67339	85943	78.4	55687	77912	71.5
17	62100	75591	82.2	59413	73452	80.9	47167	64895	72.7
18	51530	65580	78.6	50039	64924	77.1	45521	66236	68.7
19	46894	58298	80.4	48160	61272	78.6	40848	58894	69.4
20	40731	50197	81.1	46380	58928	78.7	37556	54563	68.8
21	41564	51508	80.7	45495	58009	78.4	26721	40507	66.0
22	39040	47150	82.8	41172	51191	80.4	24188	36374	66.5
23	34874	41810	83.4	30103	36939	81.5	29318	43029	68.1

Non Sealed-TEST1				Non Sealed-TEST2			Non Sealed-TEST3		
Constant flow rate:50L/min				Constant flow rate:50L/min			Constant flow rate:50L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%
1	310523	400900	77.5	306412	396851	77.2	316470	417099	75.9
2	306140	423262	72.3	295845	410305	72.1	327526	462133	70.9
3	266559	428400	62.2	275914	445200	62.0	234172	386400	60.6
4	211101	330182	63.9	222253	349416	63.6	174223	282099	61.8
5	182886	234351	78.0	210072	270968	77.5	170750	227028	75.2
6	181525	227142	79.9	153755	193177	79.6	166661	216529	77.0
7	144484	191243	75.5	150728	201000	75.0	139434	193195	72.2
8	137107	192715	71.1	128629	182008	70.7	108174	160596	67.4
9	120218	176166	68.2	116008	171361	67.7	84825	132926	63.8
10	91220	133449	68.4	108153	160423	67.4	83778	132031	63.5
11	70644	111495	63.4	69644	111495	62.5	84364	144578	58.4
12	67355	115285	58.4	63080	109463	57.6	66097	124602	53.0
13	69976	102805	68.1	69631	103803	67.1	56926	92825	61.3
14	62224	86671	71.8	60107	85051	70.7	45119	71281	63.3
15	73434	73446	100.0	76172	77232	98.6	69941	76476	91.5
16	50546	60559	83.5	55051	67498	81.6	44547	61191	72.8

Non Sealed-TEST1				Non Sealed-TEST2			Non Sealed-TEST3		
Constant flow rate:80L/min				Constant flow rate:80L/min			Constant flow rate:80L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%
1	315916	428042	73.8	311750	423718	73.6	322080	445337	72.3
2	321599	411259	78.2	310831	398670	78.0	344405	449029	76.7
3	312261	439398	71.1	323409	456629	70.8	275393	396321	69.5
4	300979	437029	68.9	317366	462487	68.6	251012	373384	67.2
5	314255	400320	78.5	361966	462870	78.2	298013	387810	76.8
6	295230	402943	73.3	250457	342690	73.1	275052	384115	71.6
7	201189	273680	73.5	210326	287643	73.1	196717	276474	71.2
8	185617	221025	84.0	174444	208746	83.6	148598	184188	80.7

9	166013	191962	86.5	160554	186726	86.0	119379	144845	82.4
10	123343	153431	80.4	146769	184444	79.6	115559	151800	76.1
11	101695	134876	75.4	100695	134876	74.7	124628	174895	71.3
12	95686	125310	76.4	89980	118981	75.6	96717	135437	71.4
13	79677	115702	68.9	79427	116826	68.0	65685	104470	62.9
14	71176	101396	70.2	68893	99501	69.2	52482	83392	62.9
15	55269	74607	74.1	56990	78453	72.6	50947	77685	65.6
16	46581	62228	74.9	50632	69358	73.0	40541	62877	64.5
17	42747	60679	70.4	40608	58962	68.9	30552	52093	58.6
18	34430	47615	72.3	33110	47138	70.2	28250	48092	58.7
19	30369	40523	74.9	30791	42590	72.3	24154	40937	59.0
Non sealed-TEST1				Non sealed-TEST2			Non sealed-TEST3		
Cyclic flow rate:15 L/min				Cyclic flow rate:15 L/min			Cyclic flow rate:15 L/min		

Sample	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%
1	328490	381858	86.0	360418	420430	85.7	298941	354859	84.2
2	267801	291501	91.9	301994	330170	91.5	242352	270681	89.5
3	257278	262571	98.0	228802	234254	97.7	263268	275443	95.6
4	248876	251106	99.1	247876	251106	98.7	220848	229166	96.4
5	212771	224871	94.6	224913	238925	94.1	219414	238926	91.8
6	216196	232806	92.9	215196	232806	92.4	167756	187116	89.7
7	177067	195118	90.7	202786	224983	90.1	154536	177199	87.2
8	173202	194238	89.2	145332	163663	88.8	155639	181649	85.7
9	150860	176921	85.3	128280	151187	84.8	125479	154405	81.3
10	121265	138549	87.5	132899	153288	86.7	124873	150341	83.1
11	108120	122704	88.1	123369	141582	87.1	116709	140234	83.2
12	102822	116934	87.9	104862	120478	87.0	96323	116935	82.4
13	97776	104560	93.5	100476	108621	92.5	79251	91364	86.7
14	87737	103656	84.6	83550	99781	83.7	67695	87188	77.6
15	74966	85777	87.4	75460	87545	86.2	73697	91968	80.1
16	66384	76004	87.3	70042	81546	85.9	63212	79963	79.1
17	67984	75716	89.8	68220	77145	88.4	49130	61431	80.0
18	58283	67791	86.0	66208	78637	84.2	42858	56945	75.3
19	51416	57370	89.6	58403	66736	87.5	39926	51517	77.5
20	46081	50568	91.1	44607	50019	89.2	51425	64311	80.0
21	46628	53292	87.5	43914	51222	85.7	37987	50706	74.9
22	43699	50541	86.5	37991	44765	84.9	36023	49098	73.4
23	38582	38906	99.2	37582	38906	96.6	28931	35507	81.5
Non sealed-TEST1				Non sealed-TEST2			Non sealed-TEST3		
Cyclic flow rate:30L/min				Cyclic flow rate:30L/min			Cyclic flow rate:30L/min		

Sample	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%
1	287026	400383	71.7	291833	392533	74.3	292140	384683	75.9
2	263860	324566	81.3	207200	257833	80.4	254940	327600	77.8
3	243983	280635	86.9	170538	191229	89.2	244069	273185	89.3
4	198756	210331	94.5	241600	265802	90.9	185993	217266	85.6
5	164485	204465	80.4	206206	250143	82.4	163326	197940	82.5
6	162073	211276	76.7	157849	197055	80.1	163633	201119	81.4
7	148621	192814	77.1	132016	168942	78.1	144960	189142	76.6
8	135891	169129	80.3	114945	150889	76.2	123159	177420	69.4
9	115408	165920	69.6	113244	148863	76.1	120550	150415	80.1
10	102681	141718	72.5	106899	138966	76.9	103487	132088	78.3
11	100579	122715	82.0	89401	117757	75.9	87603	131393	66.7
12	91203	105313	86.6	87541	99178	88.3	87365	102246	85.4
13	69402	83638	83.0	65671	72796	90.2	69730	75895	91.9

	Non sealed-TEST1 Cyclic flow rate:50L/min			Non sealed-TEST2 Cyclic flow rate:50L/min			Non sealed-TEST3 Cyclic flow rate:50L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%
1	297902	497580	59.9	309340	495591	62.4	325607	498078	65.4
2	311703	485568	64.2	287366	482179	59.6	276033	484601	57.0
3	266569	487595	54.7	248611	482253	51.6	211617	487110	43.4
4	228440	438281	52.1	211156	339569	62.2	171053	406694	42.1
5	161800	283505	57.1	169552	352045	48.2	193813	299084	64.8
6	166927	250167	66.7	172312	218592	78.8	139675	259883	53.7
7	143601	220993	65.0	137068	216660	63.3	134335	212327	63.3
8	136782	225305	60.7	137037	178981	76.6	102674	227412	45.1
9	133413	224172	59.5	128938	152754	84.4	85207	218222	39.0
10	90201	160055	56.4	92092	202267	45.5	106832	165332	64.6
11	78445	154285	50.8	75021	188752	39.7	88912	149362	59.5
12	78530	148099	53.0	73874	138130	53.5	66913	140979	47.5
13	69084	132819	52.0	66816	116375	57.4	54341	130290	41.7
14	62581	116785	53.6	64526	104191	61.9	49602	122511	40.5
15	57138	114161	50.1	51032	102425	49.8	45022	103493	43.5
16	51422	93184	55.2	47098	91374	51.5	43973	86852	50.6
17	49486	81801	60.5	51808	78496	66.0	41088	87586	46.9
18	44018	75384	58.4	41809	70993	58.9	35100	73189	48.0
19	44317	62363	71.1	39445	54279	72.7	32397	56590	57.2
20	44684	74565	59.9	34956	59138	59.1	29457	59139	49.8
21	40614	66027	61.5	35937	48072	74.8	23751	59657	39.8
22	28371	43309	65.5	31351	49496	63.3	25568	49973	51.2

23	29658	48446	61.2	29755	47957	62.0	22885	50405	45.4
	Non sealed-TEST1			Non sealed-TEST2			Non sealed-TEST3		
	Cyclic flow rate:85L/min			Cyclic flow rate:85L/min			Cyclic flow rate:85L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%	Inside (pt/cc)	Outside (pt/cc)	P(Cin/Cout)%
1	222569	465959	47.8	213023	484785	43.9	205387	461253	44.5
2	199867	438039	45.6	200821	433744	46.3	185551	416567	44.5
3	175330	280370	62.5	156224	313179	49.9	162246	301249	53.9
4	146257	212147	68.9	121530	254083	47.8	150923	273819	55.1
5	119937	250671	47.8	139734	212959	65.6	107322	201869	53.2
6	103919	172980	60.1	86806	205654	42.2	93629	197966	47.3
7	82542	186293	44.3	83176	182567	45.6	79310	190019	41.7
8	88727	115292	77.0	69364	146489	47.4	81429	145133	56.1
9	74500	97930	76.1	51900	139901	37.1	69965	143717	48.7
10	59894	130060	46.1	71716	106310	67.5	51563	102918	50.1
11	52750	81012	65.1	64105	65009	98.6	47907	66220	72.3
12	49958	91079	54.9	47999	92957	51.6	45856	97652	47.0

	Nose only sealed-TEST1			Nose only sealed-TEST2			Nose only sealed-TEST3		
	Constant flow rate:15L/min			Constant flow rate:15L/min			Constant flow rate:15L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	88462	500000	17.7	96929	500000	19.4	68625	500000	19.4
2	42228	495804	8.5	38171	433828	8.8	41319	500572	8.8
3	55477	488215	11.4	49796	432946	11.5	49662	460581	11.5
4	61635	461400	13.4	62222	465880	13.4	52024	416605	13.4
5	59935	273824	21.9	65437	299495	21.8	58020	282382	21.8
6	44993	313864	14.3	42949	299197	14.4	34703	266932	14.4
7	31802	261182	12.2	34608	285168	12.1	27118	253188	12.1
8	29278	251544	11.6	27980	239899	11.7	20598	207292	11.7
9	21855	254637	8.6	19794	229174	8.6	14547	210655	8.6
10	26520	209573	12.7	28939	229639	12.6	25190	229640	12.6
11	22999	185528	12.4	27063	220188	12.3	21641	205917	12.3
12	16606	195834	8.5	19243	229463	8.4	10686	168142	8.4
13	28846	198940	14.5	31794	220186	14.4	19739	160312	14.4
14	12486	186246	6.7	10805	158396	6.8	8212	177544	6.8
15	9756	150405	6.5	9932	153506	6.5	6621	161260	6.5
16	7274	144976	5.0	7085	140445	5.0	4466	167629	5.0
17	11345	138846	8.2	11059	134916	8.2	6167	119199	8.2
18	14739	122359	12.0	16222	135818	11.9	9506	108900	11.9

19	18600	106103	17.5	17184	97442	17.6	17330	121262	17.6
20	7777	96321	8.1	8628	108884	7.9	4879	108885	7.9
21	14063	101084	13.9	14063	101084	13.9	9194	92252	13.9
22	22723	91634	24.8	23746	95998	24.7	14884	74181	24.7
23	7525	84052	9.0	7160	79155	9.0	3593	81604	9.0
24	8660	70306	12.3	8131	65284	12.5	5894	79633	12.5
25	7880	62210	12.7	7745	60940	12.7	4672	67289	12.7
26	7070	58688	12.0	7370	61714	11.9	3560	61110	11.9
27	9392	56710	16.6	10198	62325	16.4	4595	49412	16.4
28	6018	56197	10.7	6104	57209	10.7	765	38478	10.7
29	4014	43881	9.1	4291	48269	8.9	809	52513	8.9
30	7232	44239	16.3	7081	43122	16.4	3111	41491	16.4
Nose only sealed-TEST1				Nose only sealed-TEST2			Nose only sealed-TEST3		
Constant flow rate:30L/min				Constant flow rate:30L/min			Constant flow rate:30L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	51270	500000	10.3	52251	500000	10.5	43598	500000	8.7
2	31526	493529	6.4	27741	431838	6.4	28068	498276	5.6
3	14526	506067	2.9	13023	448776	2.9	10025	477422	2.1
4	8966	506433	1.8	9041	511350	1.8	4468	457266	1.0
5	6895	335222	2.1	7425	366649	2.0	3323	345699	1.0
6	14140	327617	4.3	13537	312308	4.3	8463	278629	3.0
7	15058	251928	6.0	16326	275064	5.9	10886	244217	4.5
8	4385	246957	1.8	4240	235523	1.8	84	203511	0.0
9	10622	241810	4.4	9684	217629	4.4	5254	200044	2.6
10	12168	202673	6.0	13213	222078	5.9	9464	222079	4.3
11	5365	174932	3.1	6133	207611	3.0	2068	194156	1.1
12	2041	184221	1.1	2391	215855	1.1	1753	158170	1.1
13	12589	176337	7.1	13800	195169	7.1	6638	142097	4.7
14	9096	177352	5.1	7923	150832	5.3	4980	169065	2.9
15	10207	144620	7.1	10392	147602	7.0	7105	155057	4.6
16	10753	134511	8.0	10456	130307	8.0	8488	155529	5.5
17	986	126750	0.8	958	123163	0.8	848	108815	0.8
18	1958	117615	1.7	2173	130552	1.7	1743	104678	1.7
19	736	87474	0.8	833	98884	0.8	4011	120960	3.3
20	1425	89538	1.6	1425	89538	1.6	834	98885	0.8
21	992	71791	1.4	935	67609	1.4	1301	81716	1.6
22	762	66057	1.2	707	61339	1.2	492	67117	0.7
23	686	59657	1.1	672	58440	1.1	964	69700	1.4
24	2012	66057	3.0	1957	61339	3.2	864	74821	1.2
25	1936	59657	3.2	1922	58440	3.3	742	64528	1.1

Nose only sealed-TEST1				Nose only sealed-TEST2			Nose only sealed-TEST3		
Constant flow rate:50L/min				Constant flow rate:50L/min			Constant flow rate:50L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	50655	500000	10.1	51144	500000	10.2	44949	500000	9.0
2	34466	458024	7.5	30314	462428	6.6	31036	400772	7.7
3	24551	317215	7.7	21914	299260	7.3	19483	281305	6.9
4	33018	267502	12.3	33326	241531	13.8	26184	270100	9.7
5	15192	224201	6.8	16499	231207	7.1	11878	245221	4.8
6	13018	244869	5.3	12468	208253	6.0	7510	233427	3.2
7	14928	201988	7.4	16185	195805	8.3	10761	220539	4.9
8	13171	196053	6.7	12619	161562	7.8	7324	186977	3.9
9	19013	172312	11.0	17237	142549	12.1	12196	155082	7.9
10	9186	129929	7.1	9946	142369	7.0	6197	142370	4.4
11	7376	110569	6.7	8520	122720	6.9	4300	131226	3.3
12	5789	106816	5.4	6568	91710	7.2	1398	125159	1.1
13	5089	85548	5.9	5499	68937	8.0	595	94685	0.6
14	5563	80849	6.9	4918	77071	6.4	1612	68760	2.3
15	4488	64417	7.0	4555	69066	6.6	973	65746	1.5
16	5998	58532	10.2	5849	67677	8.6	2991	56704	5.3
17	5093	54788	9.3	4984	47035	10.6	800	53238	1.5
18	2261	48076	4.7	2509	42787	5.9	2013	53365	3.8
19	2064	42684	4.8	1896	48782	3.9	2360	39201	6.0
20	1723	35213	4.9	1947	39807	4.9	1948	39808	4.9
21	1923	35898	5.4	1923	32761	5.9	1755	35899	4.9
22	1316	33372	3.9	1379	27015	5.1	1066	34962	3.0
Nose only sealed-TEST1				Nose only sealed-TEST2			Nose only sealed-TEST3		
Constant flow rate:80L/min				Constant flow rate:80L/min			Constant flow rate:80L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	47433	500000	9.5	40897	500000	8.2	42377	500000	8.5
2	37128	382031	9.7	37473	385704	9.7	28895	334278	8.6
3	27245	268032	10.2	25774	252861	10.2	20553	237690	8.6
4	23347	214060	10.9	21202	193278	11.0	19813	216140	9.2
5	17987	195646	9.2	18510	201760	9.2	15807	213988	7.4
6	15260	206746	7.4	13165	175831	7.5	10856	197086	5.5
7	13565	158176	8.6	13188	153334	8.6	10947	172704	6.3
8	17738	147642	12.0	14837	121668	12.2	13226	140808	9.4
9	13907	114395	12.2	11721	94636	12.4	8892	102957	8.6
10	9531	85927	11.1	10324	94154	11.0	6575	94155	7.0

11	8592	74691	11.5	9399	82899	11.3	6215	88646	7.0
12	4364	66845	6.5	3924	57392	6.8	1150	78325	1.5
13	4935	60221	8.2	4219	48527	8.7	1579	66653	2.4
14	5528	54957	10.1	5328	52389	10.2	1140	46740	2.4
15	7018	41087	17.1	7434	44052	16.9	3388	41935	8.1
16	3908	34572	11.3	4323	39974	10.8	76	33493	0.2
17	2173	33383	6.5	1865	28659	6.5	2112	32439	6.5
18	1819	26726	6.8	1618	23786	6.8	2020	29666	6.8
Nose only sealed-TEST1				Nose only sealed-TEST2			Nose only sealed-TEST3		
Cyclic flow rate:15L/min				Cyclic flow rate:15L/min			Cyclic flow rate:15L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	105390	500000	21.1	98513	500000	19.7	90834	500000	18.2
2	80186	366221	21.9	92330	422563	21.8	87713	418539	21.0
3	80631	397193	20.3	85698	422546	20.3	87015	447899	19.4
4	82634	442169	18.7	74026	395401	18.7	78102	437918	17.8
5	73607	447562	16.4	69472	421987	16.5	63656	409200	15.6
6	55891	331493	16.9	49998	295744	16.9	54820	347744	15.8
7	50749	290098	17.5	45197	257564	17.5	42836	265698	16.1
8	41910	249434	16.8	36383	215530	16.9	40135	261543	15.3
9	45979	222451	20.7	42364	204475	20.7	47200	247168	19.1
10	40111	237642	16.9	40111	237642	16.9	32967	216878	15.2
11	41883	202900	20.6	39250	189749	20.7	31738	170963	18.6
12	27198	170095	16.0	20263	124638	16.3	19646	145168	13.5
13	24960	156542	15.9	18513	113973	16.2	18923	141438	13.4
14	25577	117369	21.8	28518	131556	21.7	26106	138006	18.9
15	18871	109784	17.2	19760	115328	17.1	14766	107567	13.7
16	21238	148251	14.3	25107	176945	14.2	18134	153034	11.8
17	19752	141965	13.9	17597	125426	14.0	16542	146101	11.3
18	25778	140376	18.4	20917	112553	18.6	19598	126465	15.5
19	22355	99090	22.6	27514	123313	22.3	20481	107899	19.0
20	25638	107917	23.8	25638	107917	23.8	19074	95466	20.0
21	17403	106880	16.3	15992	97540	16.4	13654	106881	12.8
22	22019	98255	22.4	17298	75924	22.8	17326	93790	18.5
23	16584	81013	20.5	17059	83519	20.4	13784	86025	16.0
24	14627	66030	22.2	17567	80542	21.8	11906	71110	16.7
25	16285	67512	24.1	17851	74544	23.9	12849	68919	18.6
26	13466	65862	20.4	13346	65216	20.5	9118	62634	14.6
27	16772	60157	27.9	13555	47692	28.4	11624	54738	21.2
28	13351	62806	21.3	9388	42241	22.2	9387	61695	15.2
29	11562	48911	23.6	12468	53211	23.4	6875	44466	15.5

30	9405	48473	19.4	9096	46638	19.5	5867	49729	11.8
31	7319	44486	16.5	7078	42724	16.6	3630	44927	8.1
Nose only sealed-TEST1				Nose only sealed-TEST2			Nose only sealed-TEST3		
Cyclic flow rate:30L/min				Cyclic flow rate:30L/min			Cyclic flow rate:30L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	58686	500000	11.7	58686	500000	11.7	54936	500000	11.0
2	36101	406661	8.9	36436	335118	10.9	27996	387835	7.2
3	46406	499249	9.3	43850	428600	10.2	37544	485120	7.7
4	26121	334656	7.8	23706	400132	5.9	22613	356482	6.3
5	26967	288596	9.3	27771	333224	8.3	25629	270746	9.5
6	19932	280398	7.1	17138	241912	7.1	15310	302390	5.1
7	17788	266329	6.7	17282	208540	8.3	15558	278892	5.6
8	20009	229040	8.7	16709	243505	6.9	15392	250739	6.1
9	15016	251645	6.0	12638	232100	5.4	9890	249203	4.0
10	13252	247482	5.4	14402	204343	7.0	10653	229319	4.6
11	9002	212622	4.2	9854	192373	5.1	6701	202498	3.3
12	11067	160622	6.9	9679	183319	5.3	9004	179828	5.0
13	9430	177117	5.3	7841	178854	4.4	6554	164963	4.0
14	2793	154117	1.8	2663	154117	1.7	2377	149541	1.6
15	13000	138027	9.4	13848	112228	12.3	9493	136738	6.9
16	4811	124833	3.9	5368	111629	4.8	951	123633	0.8
17	3861	124433	3.1	3492	95629	3.7	38	125586	0.0
18	6136	115515	5.3	5598	104300	5.4	2924	116638	2.5
19	6025	101825	5.9	6707	96834	6.9	1886	100828	1.9
20	1189	95578	1.2	1344	80103	1.7	1345	97399	1.4
21	5728	82179	7.0	5337	82179	6.5	1979	92453	2.1
22	2082	74328	2.8	1685	77331	2.2	2182	73578	3.0
23	5238	73664	7.1	5122	75108	6.8	1256	67887	1.9
24	11607	66233	17.5	12981	56043	23.2	7118	68781	10.3
25	6759	52170	13.0	7209	65806	11.0	2898	59878	4.8
26	4192	49465	8.5	4314	55848	7.7	595	54253	1.1
27	663	51310	1.3	578	39292	1.5	730	48076	1.5
28	762	52517	1.5	522	41461	1.3	777	44226	1.8
29	576	47053	1.2	690	30305	2.3	635	42269	1.5
Nose only sealed-TEST1				Nose only sealed-TEST2			Nose only sealed-TEST3		
Cyclic flow rate:50L/min				Cyclic flow rate:50L/min			Cyclic flow rate:50L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	53151	500000	10.6	56464	500000	11.3	56027	500000	11.2
2	59690	477765	12.5	68882	473215	14.6	68417	414064	16.5

3	53502	455651	11.7	60392	482990	12.5	58366	428312	13.6
4	64205	419711	15.3	57337	464842	12.3	50154	469356	10.7
5	51020	428160	11.9	41688	415185	10.0	40605	454110	8.9
6	31523	305343	10.3	39092	359029	10.9	32591	342253	9.5
7	18536	270304	6.9	24367	278840	8.7	19577	304449	6.4
8	17087	199460	8.6	17558	242042	7.3	12397	230837	5.4
9	35778	180065	19.9	38322	217661	17.6	34937	195896	17.8
10	32106	207538	15.5	35877	189404	18.9	34871	207539	16.8
11	18616	200642	9.3	19531	180776	10.8	16696	214549	7.8
12	16812	157193	10.7	16515	183084	9.0	11136	214524	5.2
13	14523	143119	10.1	13492	177605	7.6	10645	196574	5.4
14	14246	148106	9.6	13860	155366	8.9	10497	132134	7.9
15	9857	134602	7.3	11737	125542	9.3	8087	128131	6.3
16	3746	142155	2.6	4014	122945	3.3	292	119104	0.2
17	7689	99884	7.7	9706	116348	8.3	5879	113056	5.2
18	8311	93557	8.9	9146	105121	8.7	5321	116685	4.6
19	8728	106545	8.2	9037	93227	9.7	5365	85617	6.3
20	7632	87904	8.7	9010	77762	11.6	5116	87905	5.8
21	7152	73554	9.7	7889	80596	9.8	3403	80597	4.2
22	5440	58636	9.3	5236	72433	7.2	1528	75883	2.0
23	9388	64958	14.5	8605	66906	12.9	5482	63010	8.7
24	6728	61556	10.9	7974	54346	14.7	3976	50465	7.9
25	7815	55453	14.1	7224	51268	14.1	2706	50223	5.4
26	5357	50260	10.7	5240	48270	10.9	1139	50759	2.2
27	3615	39507	9.2	4144	45343	9.1	590	49834	1.2
28	3820	29614	12.9	3991	43253	9.2	756	44033	1.7
29	3614	40002	9.0	4547	33427	13.6	1171	36770	3.2
30	4923	32850	15.0	5239	35027	15.0	1687	34144	4.9

Nose only sealed-TEST1				Nose only sealed-TEST2			Nose only sealed-TEST3		
Cyclic flow rate:85L/min				Cyclic flow rate:85L/min			Cyclic flow rate:85L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	45782	500000	9.2	64709	500000	12.9	56506	500000	11.3
2	25728	518874	5.0	29579	513932	5.8	27205	449692	6.0
3	24007	363795	6.6	27008	385622	7.0	24009	341968	7.0
4	10837	261390	4.1	9791	289496	3.4	5519	292308	1.9
5	8646	227810	3.8	7259	220907	3.3	3906	241618	1.6
6	4738	206843	2.3	5610	243211	2.3	1544	231846	0.7
7	5517	208777	2.6	6957	215370	3.2	2951	235150	1.3
8	10650	169888	6.3	10929	206156	5.3	6342	196613	3.2
9	15751	174932	9.0	16820	211456	8.0	13223	190311	6.9
10	7015	177587	4.0	7720	162070	4.8	4483	177588	2.5

11	13177	159731	8.2	13805	143916	9.6	10683	170802	6.3
12	6140	114028	5.4	6047	132809	4.6	1786	155616	1.1
13	1332	104449	1.3	1229	129618	0.9	1320	143462	0.9
14	1448	114380	1.3	1405	119987	1.2	1449	102046	1.4
15	1242	101055	1.2	1513	94253	1.6	1528	96198	1.6
16	5598	98887	5.7	6066	85524	7.1	2364	82852	2.9
17	665	72013	0.9	874	83884	1.0	867	81511	1.1
18	4017	63969	6.3	4345	71876	6.0	566	79783	0.7
19	5554	74805	7.4	5732	65455	8.8	2027	60112	3.4
20	698	62999	1.1	849	55729	1.5	834	63000	1.3
21	2049	50988	4.0	2305	55870	4.1	2050	55871	3.7
22	4035	42104	9.6	3899	52011	7.5	177	54489	0.3
23	1305	40780	3.2	1179	42003	2.8	1281	39557	3.2
24	415	43796	0.9	509	38666	1.3	491	35905	1.4
25	2256	36691	6.1	2053	33922	6.1	1790	33231	5.4

Nose and chin sealed-TEST1				Nose and chin sealed-TEST2			Nose and chin sealed-TEST3		
Constant flow rate :15L/min				Constant flow rate :15L/min			Constant flow rate :15L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	1689	401058	0.42	1185	358638	0.33	1571	397202	0.40
2	1124	332549	0.34	971	255570	0.38	1180	335629	0.35
3	764	223440	0.34	675	201747	0.33	787	225611	0.35
4	781	210510	0.37	876	200191	0.44	734	208447	0.35
5	432	217909	0.20	532	182629	0.29	461	222061	0.21
6	397	179280	0.22	317	179280	0.18	369	201690	0.18
7	273	154341	0.18	204	160577	0.13	261	152782	0.17
8	235	134283	0.18	228	136916	0.17	215	123751	0.17
9	169	94739	0.18	157	80164	0.20	171	98384	0.17
10	190	80780	0.24	170	101893	0.17	207	92714	0.22
11	134	74642	0.18	127	84274	0.15	141	81867	0.17
12	145	76032	0.19	148	58223	0.25	130	71238	0.18
13	103	66188	0.16	112	52254	0.21	112	55738	0.20
14	74	57601	0.13	76	37099	0.20	77	51744	0.15
15	77	44040	0.17	63	38639	0.16	79	41964	0.19
Nose and chin sealed-TEST1				Nose and chin sealed-TEST2			Nose and chin sealed-TEST3		
Constant flow rate:30L/min				Constant flow rate:30L/min			Constant flow rate:30L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	2010	432197	0.47	1517	332151	0.46	2163	436200	0.50

2	2134	298545	0.71	1758	269560	0.65	2036	301444	0.68
3	1681	294082	0.57	1443	279666	0.52	1634	291200	0.56
4	966	220027	0.44	1156	184404	0.63	1030	224219	0.46
5	712	206304	0.35	823	206304	0.40	669	232092	0.29
6	595	203081	0.29	513	211286	0.24	643	201031	0.32
7	499	183531	0.27	390	187130	0.21	523	169138	0.31
8	376	157300	0.24	399	133100	0.30	412	163350	0.25
9	317	110146	0.29	292	138934	0.21	315	126418	0.25
10	269	100254	0.27	222	113190	0.20	250	109956	0.23
11	222	101920	0.22	201	78047	0.26	212	95493	0.22
12	167	89411	0.19	191	70587	0.27	188	75294	0.25
13	151	77143	0.20	153	49685	0.31	142	69299	0.20
14	125	57982	0.22	125	50871	0.25	122	55247	0.22
15	104	45232	0.23	85	43441	0.20	104	45681	0.23
16	59	22867	0.26	53	26347	0.20	59	25354	0.23
Nose and chin sealed-TEST1				Nose and chin sealed-TEST2			Nose and chin sealed-TEST3		
Constant flow rate:50L/min				Constant flow rate:50L/min			Constant flow rate:50L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	2032	360045	0.56	1533	312039	0.49	2186	356616	0.61
2	1145	311616	0.37	1307	334338	0.39	1283	327846	0.39
3	1140	225933	0.50	1176	214523	0.55	1212	244192	0.50
4	1178	205224	0.57	1155	181080	0.64	1132	217296	0.52
5	1108	197916	0.56	1077	186497	0.58	952	186498	0.51
6	923	160514	0.58	923	215235	0.43	1070	171459	0.62
7	520	155124	0.34	434	165132	0.26	561	180144	0.31
8	526	179705	0.29	420	142469	0.29	503	163516	0.31
9	391	181591	0.22	346	133804	0.26	381	162477	0.23
10	277	163904	0.17	323	108343	0.30	306	144459	0.21
11	281	140060	0.20	270	129490	0.21	276	126848	0.22
12	226	121609	0.19	215	111976	0.19	231	127630	0.18
13	222	100616	0.22	203	117021	0.17	198	110460	0.18
14	153	94803	0.16	145	74305	0.20	146	87118	0.17
15	292	80721	0.36	233	60719	0.38	288	72864	0.40
16	237	53938	0.44	217	47653	0.46	238	55510	0.43
17	121	41335	0.29	105	36472	0.29	130	43767	0.30
Nose and chin sealed-TEST1				Nose and chin sealed-TEST2			Nose and chin sealed-TEST3		
Constant flow rate:80L/min				Constant flow rate:80L/min			Constant flow rate:80L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	3299	340984	0.97	2490	377649	0.66	3549	381316	0.93

2	2736	303614	0.90	2255	398722	0.57	2611	395064	0.66
3	2495	321026	0.78	2142	358997	0.60	2425	355546	0.68
4	1564	278983	0.56	1871	290488	0.64	1667	293365	0.57
5	2423	221085	1.10	2797	268820	1.04	2274	263796	0.86
6	2334	192528	1.21	2014	216594	0.93	2518	192528	1.31
7	1428	196066	0.73	1118	186548	0.60	1497	188453	0.79
8	1132	177840	0.64	1203	160740	0.75	1240	174420	0.71
9	1255	144594	0.87	1158	177456	0.65	1244	170885	0.73
10	890	141376	0.63	735	128639	0.57	826	112083	0.74
11	646	117500	0.55	585	114143	0.51	616	104072	0.59
12	511	79090	0.65	583	96769	0.60	573	103284	0.55
13	383	62082	0.62	387	66221	0.58	358	78639	0.46
14	261	40059	0.65	261	55872	0.47	254	62198	0.41
15	215	35378	0.61	174	38421	0.45	214	40324	0.53

Nose and chin sealed-TEST1				Nose and chin sealed-TEST2			Nose and chin sealed-TEST3		
Cyclic flow rate:15L/min				Cyclic flow rate:15L/min			Cyclic flow rate:15L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	177	497765	0.04	181	484020	0.04	208	490893	0.04
2	209	498646	0.04	184	479281	0.04	210	474441	0.04
3	362	522540	0.07	307	465536	0.07	366	437035	0.08
4	114	388242	0.03	106	400250	0.03	116	412258	0.03
5	104	263053	0.04	95	300632	0.03	95	303524	0.03
6	67	252703	0.03	59	265865	0.02	71	271130	0.03
7	54	259096	0.02	56	254016	0.02	54	248936	0.02
8	31	242719	0.01	27	198986	0.01	34	214293	0.02
9	70	202213	0.03	53	161055	0.03	72	173582	0.04
10	35	153603	0.02	27	151762	0.02	30	154985	0.02
11	21	129694	0.02	18	114451	0.02	18	143388	0.01
12	20	105565	0.02	24	112881	0.02	22	95114	0.02
13	13	88408	0.01	13	89310	0.01	15	92920	0.02
14	227	82903	0.27	245	64978	0.38	263	76182	0.35
15	13	68374	0.02	13	48406	0.03	13	64744	0.02
16	9	43834	0.02	8	41281	0.02	9	42558	0.02
17	5	37905	0.01	6	39763	0.02	7	33818	0.02

Nose and chin sealed-TEST1				Nose and chin sealed-TEST2			Nose and chin sealed-TEST3		
Cyclic flow rate:30L/min				Cyclic flow rate:30L/min			Cyclic flow rate:30L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	428	500000	0.09	238	500000	0.05	48	500000	0.01
2	349	431715	0.08	167	502877	0.03	35	488646	0.01

3	169	295366	0.06	96	331872	0.03	43	368378	0.01
4	102	279175	0.04	78	244278	0.03	45	224338	0.02
5	67	233381	0.03	47	201417	0.02	21	221998	0.01
6	24	179115	0.01	41	196264	0.02	57	196265	0.03
7	5	130275	0.00	62	160928	0.04	107	168592	0.06
8	16	129066	0.01	27	132937	0.02	37	125195	0.03
9	84	115021	0.07	166	101550	0.16	254	94297	0.27
10	21	98055	0.02	15	90654	0.02	9	88805	0.01
11	16	73985	0.02	10	71055	0.01	4	74719	0.01
12	15	53572	0.03	10	61486	0.02	1	67575	0.00
13	7	37065	0.02	7	54134	0.01	6	55111	0.01
14	18	45575	0.04	15	38084	0.04	18	41893	0.04
15	8	33090	0.02	8	35282	0.02	10	34393	0.03

Nose and chin sealed-TEST1				Nose and chin sealed-TEST2			Nose and chin sealed-TEST3		
Cyclic flow rate:50L/min				Cyclic flow rate:50L/min			Cyclic flow rate:50L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	525	500000	0.11	300	500000	0.06	50	500000	0.01
2	535	482782	0.11	256	463849	0.06	54	473316	0.01
3	351	400979	0.09	200	498996	0.04	88	436623	0.02
4	263	416128	0.06	199	437468	0.05	114	377553	0.03
5	346	384911	0.09	242	351278	0.07	104	384911	0.03
6	116	272085	0.04	197	210247	0.09	268	259718	0.10
7	12	212457	0.01	128	219028	0.06	220	225599	0.10
8	65	203126	0.03	110	247769	0.04	146	218752	0.07
9	35	181743	0.02	70	200674	0.03	108	185530	0.06
10	92	153951	0.06	67	152442	0.04	38	146406	0.03
11	118	135215	0.09	79	107198	0.07	24	123035	0.02
12	197	110599	0.18	131	74385	0.18	11	108643	0.01
13	36	76677	0.05	39	83418	0.05	30	69707	0.04
14	27	62249	0.04	23	59892	0.04	27	63862	0.04
15	19	49799	0.04	19	47826	0.04	21	50293	0.04
16	21	40161	0.05	21	38931	0.05	21	43850	0.05

Nose and chin sealed-TEST1				Nose and chin sealed-TEST2			Nose and chin sealed-TEST3		
Cyclic flow rate:85L/min				Cyclic flow rate:85L/min			Cyclic flow rate:85L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	2543	472191	0.54	1455	450126	0.32	241	401583	0.06
2	1464	377054	0.39	701	404264	0.17	147	384829	0.04
3	1278	346566	0.37	728	346566	0.21	318	346566	0.09
4	631	229216	0.28	479	229216	0.21	272	229216	0.12

5	457	197983	0.23	320	194023	0.16	138	201943	0.07
6	131	155813	0.08	223	178072	0.13	303	143094	0.21
7	16	118894	0.01	177	137762	0.13	304	131043	0.23
8	78	104306	0.07	132	95191	0.14	176	104307	0.17
9	75	94879	0.08	148	76806	0.19	227	99398	0.23
10	161	82665	0.19	118	80258	0.15	66	77851	0.08
11	142	61622	0.23	96	69796	0.14	29	57221	0.05
12	127	48323	0.26	84	52268	0.16	7	47338	0.01
13	54	37789	0.14	60	39347	0.15	44	39738	0.11

Fully sealed-TEST1				Fully sealed-TEST2			Fully sealedTEST3		
Constant flow rate :15L/min				Constant flow rate :15L/min			Constant flow rate :15L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	34	500000	0.007	9	500000	0.002	14	500000	0.003
2	24	477130	0.005	3	486769	0.001	11	481950	0.002
3	3	463354	0.001	1	477395	0.000	2	463355	0.000
4	17	394795	0.004	9	394795	0.002	12	406759	0.003
5	25	375554	0.007	8	357323	0.002	17	360970	0.005
6	0	302345	0.000	1	348623	0.000	2	274580	0.001
7	1	236621	0.000	21	241691	0.009	13	246038	0.005
8	4	207125	0.002	8	214385	0.004	9	219083	0.004
9	0	188174	0.000	1	188174	0.001	2	182585	0.001
10	1	171995	0.001	0	151851	0.000	1	141006	0.001
11	4	121416	0.003	1	148101	0.001	3	130757	0.002
12	10	115116	0.009	1	126293	0.001	6	93882	0.006
13	3	95716	0.003	2	96655	0.002	3	89148	0.003
14	2	85793	0.002	1	81784	0.001	3	72965	0.004
15	7	70488	0.010	9	71172	0.013	8	63645	0.013
16	5	52506	0.010	4	58852	0.007	6	61738	0.010
17	4	47778	0.008	3	54894	0.005	5	49812	0.010
18	3	45461	0.007	2	48521	0.004	4	37157	0.011

Fully sealed-TEST1				Fully sealed-TEST2			Fully sealedTEST3		
Constant flow rate :30L/min				Constant flow rate :30L/min			Constant flow rate :30L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	23	500000	0.005	13	500000	0.003	3	500000	0.001
2	20	494866	0.004	10	484968	0.002	3	504764	0.001
3	11	476236	0.002	6	523859	0.001	3	428613	0.001
4	8	404101	0.002	6	406550	0.001	4	413898	0.001

5	4	269790	0.001	2	267065	0.001	3	280692	0.001
6	1	237055	0.000	1	217899	0.000	4	263395	0.002
7	0	220059	0.000	1	207240	0.000	5	213650	0.002
8	0	177510	0.000	0	182944	0.000	2	182945	0.001
9	0	147209	0.000	0	150214	0.000	2	153219	0.001
10	1	122705	0.001	1	131560	0.001	1	125235	0.001
11	1	107110	0.001	1	107110	0.001	1	103929	0.001
12	1	99583	0.001	1	68183	0.001	1	101378	0.001
13	0	68827	0.000	0	82366	0.000	0	75711	0.000
14	1	66114	0.002	0	62006	0.000	2	64446	0.003
15	0	55360	0.000	0	52646	0.000	2	54818	0.004
16	0	49295	0.000	0	43767	0.000	0	45150	0.000
Fully sealed-TEST1				Fully sealed-TEST2			Fully sealedTEST3		
Constant flow rate :50L/min				Constant flow rate :50L/min			Constant flow rate :50L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	9	500000	0.002	5	500000	0.001	1	500000	0.000
2	7	482483	0.001	3	477706	0.001	1	472929	0.000
3	3	456964	0.001	1	443655	0.000	1	430346	0.000
4	2	405408	0.000	2	397612	0.001	2	366428	0.001
5	3	250105	0.001	1	220680	0.000	2	264818	0.001
6	0	239884	0.000	0	231659	0.000	2	213840	0.001
7	0	202949	0.000	0	193553	0.000	3	167246	0.002
8	0	162301	0.000	0	163790	0.000	2	120609	0.002
9	0	130425	0.000	0	117500	0.000	0	104575	0.000
10	1	107123	0.001	1	96602	0.001	1	83213	0.001
11	36	94163	0.038	24	82091	0.029	8	65191	0.012
12	0	56253	0.000	0	62573	0.000	0	70791	0.000
13	6	56521	0.011	6	49456	0.012	5	45420	0.011
14	4	44564	0.009	3	45367	0.007	5	30513	0.016
Fully sealed-TEST1				Fully sealed-TEST2			Fully sealedTEST3		
Constant flow rate :80L/min				Constant flow rate :80L/min			Constant flow rate :80L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	37	500000	0.007	21	500000	0.004	4	500000	0.001
2	20	477946	0.004	10	497454	0.002	3	487700	0.001
3	28	388967	0.007	15	385227	0.004	7	347827	0.002
4	4	332171	0.001	3	335460	0.001	2	319017	0.001
5	4	245964	0.002	2	255516	0.001	3	214920	0.001
6	1	214430	0.000	1	210306	0.000	4	193813	0.002
7	0	156723	0.000	2	138285	0.001	10	165942	0.006

8	1	123706	0.001	2	119465	0.002	5	110276	0.005
9	1	90145	0.001	1	85972	0.001	4	74287	0.005
10	5	66293	0.008	4	66902	0.006	3	49265	0.006
11	1	53014	0.002	1	47761	0.002	1	42508	0.002
12	3	39335	0.008	2	35472	0.006	1	30556	0.003
Fully sealed-TEST1				Fully sealed-TEST2				Fully sealedTEST3	
Cyclic flow rate:15L/min				Cyclic flow rate:15L/min			Cyclic flow rate:15L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	88	500000	0.018	50	500000	0.010	9	500000	0.002
2	70	485694	0.014	33	495506	0.007	8	490600	0.002
3	28	465553	0.006	15	412848	0.004	7	439201	0.002
4	8	375656	0.002	6	379303	0.002	4	339185	0.001
5	31	265584	0.012	14	193655	0.007	17	370713	0.005
6	33	253405	0.013	44	189462	0.023	90	267616	0.034
7	7	219755	0.003	44	134544	0.033	171	318421	0.054
8	14	218864	0.006	20	178333	0.011	35	210759	0.017
9	21	213811	0.010	42	192430	0.022	65	176881	0.037
10	57	171662	0.033	42	188098	0.022	24	188099	0.013
11	97	151840	0.064	65	180206	0.036	20	168527	0.012
12	56	134271	0.042	37	157328	0.024	3	115284	0.003
13	12	128983	0.009	12	125227	0.010	12	121471	0.010
14	10	125560	0.008	11	119692	0.009	11	106785	0.010
15	9	93784	0.010	9	99585	0.009	9	96685	0.009
16	18	90777	0.020	18	96451	0.019	18	96452	0.019
17	21	95532	0.022	22	96433	0.023	19	78409	0.024
18	22	86724	0.025	22	85056	0.026	21	78386	0.027
19	54	76104	0.071	47	67150	0.070	58	80581	0.072
20	13	70949	0.018	13	68516	0.019	13	63247	0.021
21	16	60519	0.026	15	57718	0.026	14	49873	0.028
22	6	64366	0.009	6	64957	0.009	5	47833	0.010
23	23	58171	0.040	21	52407	0.040	19	46643	0.041
24	33	49654	0.066	30	44777	0.067	27	38571	0.070
25	47	48168	0.098	41	41993	0.098	34	33348	0.102
26	27	35223	0.077	30	39181	0.077	35	44327	0.079
27	26	40458	0.064	23	35401	0.065	22	32512	0.068
Fully sealed-TEST1				Fully sealed-TEST2			Fully sealedTEST3		
Cyclic flow rate:30L/min				Cyclic flow rate:30L/min				Cyclic flow rate:30L/min	

Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	93	500000	0.019	96	500000	0.019	90	500000	0.018
2	86	485660	0.018	87	490566	0.018	87	495472	0.018
3	78	461452	0.017	69	400506	0.017	74	444040	0.017
4	72	408986	0.018	72	408986	0.018	66	373250	0.018
5	59	292028	0.020	43	319405	0.013	84	301155	0.028
6	53	210126	0.025	40	202271	0.020	57	176742	0.032
7	48	179568	0.027	29	179568	0.016	70	190563	0.037
8	61	163531	0.037	50	148389	0.034	60	142333	0.042
9	49	167473	0.029	44	147681	0.030	41	141592	0.029
10	46	129128	0.036	50	138744	0.036	51	144240	0.035
11	38	121672	0.031	45	148413	0.030	43	131032	0.033
12	40	126617	0.032	47	116385	0.040	35	140686	0.025
13	41	124725	0.033	40	124725	0.032	39	113828	0.034
14	40	107864	0.037	38	102824	0.037	35	91736	0.038
15	35	84660	0.041	38	93388	0.041	37	83788	0.044
16	30	77425	0.039	32	80652	0.040	33	83879	0.039
17	24	70801	0.034	24	60782	0.039	21	68798	0.031
18	26	61953	0.042	25	55996	0.045	24	60763	0.039
19	28	56122	0.050	25	49519	0.050	31	59424	0.052
20	21	53607	0.039	20	51769	0.039	19	47788	0.040
21	20	53342	0.037	19	50872	0.037	17	43958	0.039
22	19	45770	0.042	19	46190	0.041	15	34013	0.044
23	14	39490	0.035	13	35577	0.037	12	31664	0.038
24	10	38986	0.026	9	35157	0.026	8	30284	0.026

Fully sealed-TEST1				Fully sealed-TEST2			Fully sealedTEST3		
Cyclic flow rate:50L/min				Cyclic flow rate:50L/min			Cyclic flow rate:50L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	136	497666	0.027	122	497666	0.025	132	497666	0.027
2	99	497183	0.020	88	502154	0.018	92	492212	0.019
3	95	429792	0.022	82	476509	0.017	92	495196	0.019
4	84	397768	0.021	84	363012	0.023	78	397769	0.020
5	78	377041	0.021	86	355496	0.024	82	344724	0.024
6	90	331178	0.027	87	289379	0.030	77	344041	0.022
7	80	272709	0.029	80	289406	0.028	86	272710	0.032
8	85	233061	0.036	77	223548	0.034	75	256844	0.029
9	67	208086	0.032	59	199505	0.030	57	235975	0.024
10	58	215887	0.027	62	224437	0.028	66	200925	0.033
11	53	210533	0.025	65	185876	0.035	58	172600	0.034

12	43	154517	0.028	40	186778	0.021	49	168102	0.029
13	41	112976	0.036	41	103104	0.040	38	112977	0.034
14	37	104554	0.035	35	93278	0.038	32	109680	0.029
15	29	108075	0.027	32	96964	0.033	29	97975	0.030
16	24	96411	0.025	26	100267	0.026	28	92555	0.030
17	20	83090	0.024	17	94047	0.018	20	96787	0.021
18	32	73784	0.043	29	80063	0.036	32	81634	0.039
19	21	68276	0.031	18	81932	0.022	23	77381	0.030
20	26	68612	0.038	25	63334	0.039	24	71049	0.034
21	20	58312	0.034	19	50386	0.038	17	61144	0.028
22	19	46183	0.041	19	34007	0.056	15	45764	0.033
23	17	38177	0.045	16	33977	0.047	15	42377	0.035
24	15	42128	0.036	14	36288	0.039	13	46717	0.028

Fully sealed-TEST1				Fully sealed-TEST2			Fully sealedTEST3		
Cyclic flow rate:85L/min				Cyclic flow rate:85L/min			Cyclic flow rate:85L/min		
Sample	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)	Inside (pt/cc)	Outside (pt/cc)	% P(Cin/Cout)
1	94	480338	0.020	84	470827	0.018	91	475583	0.019
2	100	461835	0.022	89	457170	0.019	93	480495	0.019
3	84	462229	0.018	73	435039	0.017	82	462230	0.018
4	70	437544	0.016	70	433296	0.016	64	403560	0.016
5	57	399183	0.014	63	428290	0.015	60	419975	0.014
6	47	433561	0.011	45	417045	0.011	40	388142	0.010
7	39	395549	0.010	39	383800	0.010	42	395550	0.011
8	42	357481	0.012	38	330502	0.011	37	323758	0.011
9	36	331763	0.011	32	312437	0.010	31	322100	0.010
10	31	205597	0.015	33	220908	0.015	35	229658	0.015
11	23	199957	0.012	28	235114	0.012	26	224128	0.012
12	230	181870	0.126	212	167174	0.127	257	202079	0.127
13	20	185657	0.011	20	185657	0.011	19	169435	0.011
14	22	155131	0.014	21	147882	0.014	20	131935	0.015
15	21	104204	0.020	23	114946	0.020	22	103130	0.021
16	16	76649	0.021	17	79843	0.021	18	83037	0.022
17	18	65513	0.027	15	56242	0.027	18	63660	0.028
18	18	59634	0.030	16	53900	0.030	19	58488	0.032
19	15	53517	0.028	13	47221	0.028	17	56666	0.030
20	13	53098	0.024	13	51277	0.025	13	47334	0.027